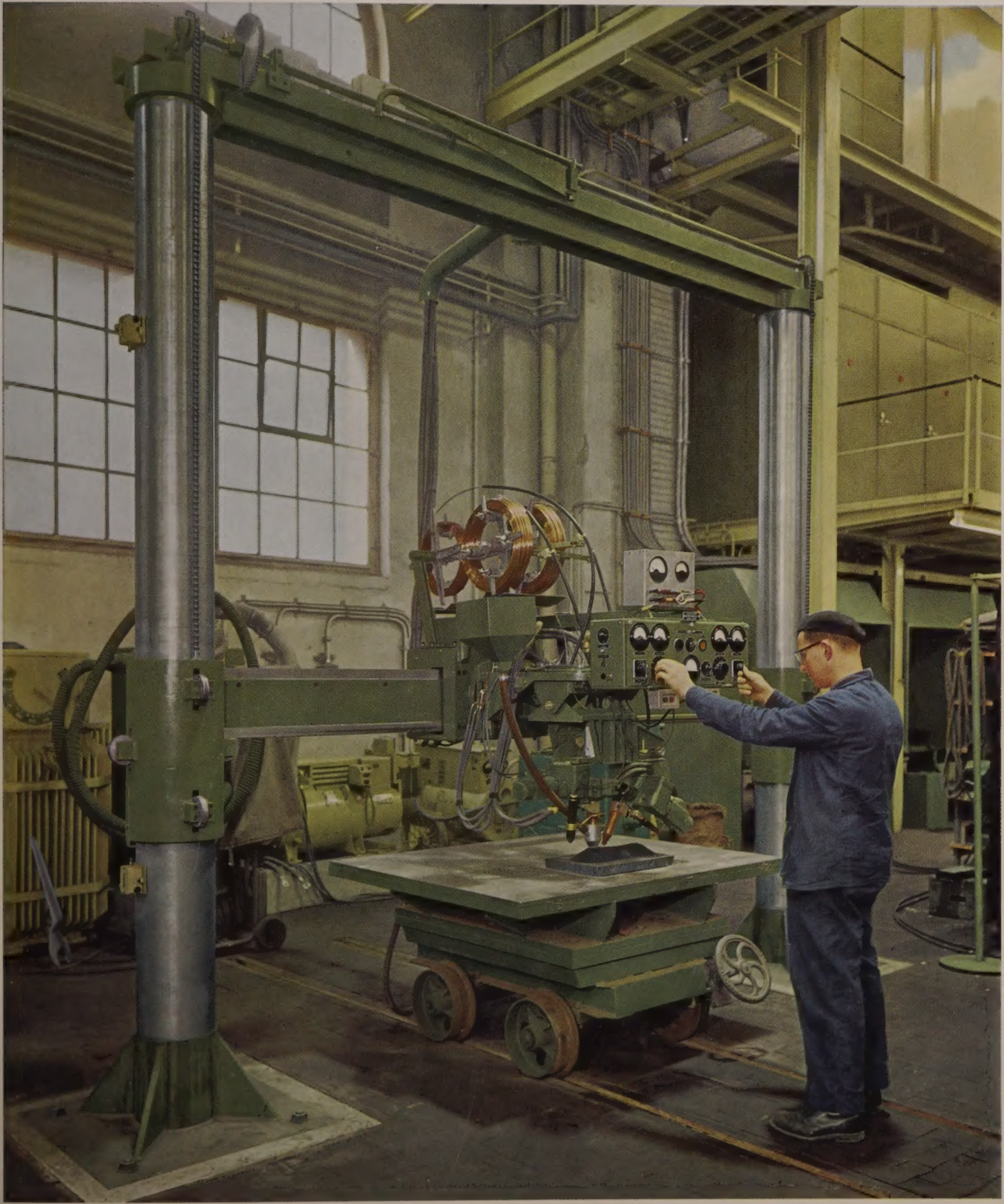
BROWN BOVERI REVIEW

Electric Welding



BROWN BOVERI REV. VOL. 48 No. 8/9 p. 417–528 BADEN, AUGUST/SEPTEMBER 1961

Printed in Switzerland

Front cover: Brown Boveri multi-purpose automatic welding installation type K 1200 in the welding laboratory of Sulzer Bros., Winterthur

THE BROWN BOVERI REVIEW

ISSUED BY BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)

VOL. 48 AUGUST/SEPTEMBER 1961 No. 8/9

CONTENTS:

REQUIREMENTS IMPOSED ON THE CURRENT SOURCES WHEN WELDING WITH DEEP-PENETRATION AND HIGH-DEPOSIT ELECTRODES

621.791.75.04:621.311.6

There are now a number of special electrodes available for manual arc welding, which afford better penetration or a greater deposit than normal electrodes. The article describes the features of these electrodes and explains the special requirements which their use imposes on the sources of welding current and their manipulation.

Deep-Penetration and High-Deposit Electrodes and their Employment

In an effort to improve the economics of manual welding, the manufacturers of the electrodes adopt different approaches. It is obvious that the welding performance can be improved by increasing the arc power. Fundamentally there are two possible methods of doing this: either by working at a higher voltage or higher current. When welding with ordinary electrodes having a length of 45 cm the current can only be increased within fairly close limits, otherwise the core wire would be overheated. Moreover, every good welder knows that the quality of a seam deteriorates if the current is too heavy.

There are now two categories of electrodes which —apart from a few exceptions—can be used with a higher voltage than usual for ordinary electrodes. One category comprises the deep-penetration electrodes. As the name suggests, deeper penetration is achieved with these electrodes. As a result of the deeper molten pool, produced in the actual material, there is seldom any

need to bevel the faces of the plates, and it is possible to refer in this respect to high-deposit electrodes,[1] although the actual material deposited, expressed in kg/h, remains relatively small. The other category comprises the true high-deposit electrodes, which are noteworthy for the large material deposit per hour.

By utilizing deep-penetration and high-deposit electrodes it is possible to improve the economics of manual arc welding quite appreciably because the cost of a seam is lowered, even though the electrodes themselves are more expensive than those of the ordinary type. In all situations where automatic welding is not feasible, and semi-automatic welders do not bring any advantages, such electrodes are employed.

Deep-penetration electrodes, however, have not succeeded in asserting themselves as the accuracy with which the edges have to be prepared often gives rise to difficulties. When these electrodes are used it is essential to observe very definite gap widths in relation to the thickness of the plate, although in many cases this is quite impracticable. The use of deep-penetration electrodes becomes doubtful, for high-grade welding, if the necessary depth of penetration cannot possibly be attained owing to the inaccuracy of the edges.

Advantages of a different kind are offered by the high-deposit electrodes. The very thick coating of these electrodes contains a high proportion of pulverized iron, which greatly helps to increase the deposit. With electrodes of this variety the amount of molten metal may reach 200% of the weight of the wire. They are used for fillet welds and for filling single-V and double-V butt welds. The rate of deposit is very high, e.g. up to 4 kg/h with electrodes 5 mm thick. Fillet welds up to a seam thickness of 6 mm can be welded in one run, admittedly only in the downhand position, whereas with the electrode in the 45° position a thickness of about 5 mm can be attained without the weld metal draining.

[1] The term "high-deposit electrode" is not normally used in the technical literature as these electrodes are conventionally known as iron-powder electrodes. However, to enhance the distinction between the two types of special electrodes dealt with in this article, it is considered preferable to refer to each by its function, rather than to one by its function and the other by its composition.

Features of the Special Electrodes

When welding with coated electrodes the delayed burn-off of the outer edge of the coating produces a crater in the tip of the electrode because the core wire burns away a little faster than the coating. The depth of this crater is largely dependent on the thickness of the coating and its composition. With electrodes having a thin coating a crater of this kind cannot possibly form. The depth of the crater, however, exerts a decided influence on the length of the arc and, indirectly, on the arc voltage. Thickly coated standard electrodes with a rutile covering giving a viscous slag, or with an iron oxide covering giving an inflated slag, are welded at about 26–28 V for a thickness of 4 mm. For electrodes with a basic covering or moderately thick rutile covering the arc voltage is somewhat lower.

The covering of the iron-powder electrodes is very thick indeed, up to twice as thick as normal coatings. As a result the end crater is correspondingly deeper, thereby extending the arc and increasing the arc voltage. For this type of electrode with a core wire 4 mm in diameter this voltage is about 35–40 V. But the current required for this type of electrode is also considerably higher than that for normally coated electrodes having the same core wire. In consequence the electric power consumed is likewise very much higher than for conventional types of electrodes.

With the majority of deep-penetration electrodes a deeper crater is produced, depending on the composition of the covering. The covering is indeed less thick than that of iron-powder electrodes, but somewhat thicker than that of the standard electrodes. The deep, narrow crater keeps the arc very concentrated, thus explaining its deep penetration into the material of the workpiece, although this is only achieved when the correct technique is adopted. The length of the arc grows with the depth of the crater, and with it the arc voltage. For wire with a core diameter of 4 mm it usually amounts to about 40–50 V, but may even reach 55 V. The current required for these electrodes is somewhat higher than for normal electrodes, which in turn increases the power consumption still more.

Effect of the Special Electrodes on the Source of Current

To make the process easier to understand, it is necessary to go into the relationship between the various factors affecting welding. Information regarding the capacity of the current source can usually be obtained from the rating plate. It is important to distinguish between the technical data of the motor, or the primary part, and those of the generator, or the secondary part of a transformer. In this respect the welder is only interested in the generator output or the rating of the transformer secondary. The following figures may be quoted, for instance:

Welding range	60–500 A at 22–40 V
Welding current at 100% arcing time factor	310 A at 32 V (continuous)
at 60% arcing time factor	400 A at 35 V, nominal manual welding conditions according to ISO (International Organization for Standardization)
or	
Welding current at 55% arcing time factor	420 A at 35 V, nominal manual welding conditions according to German Standards (DIN)
at 35% arcing time factor	500 A at 40 V, manual welding

The above figures indicate that the overall welding range extends from 60 to 500 A, but of course only when the relevant voltages are adhered to, i.e. 22 V at 50 A up to 40 V at 500 A. On the setting scale the currents are calibrated for the appropriate voltages. The source therefore only produces the particular current when the terminal voltage agrees with the calibration voltage (Fig. 1). These calibration voltages are values which are obtained in practice when welding with normal coated electrodes, provided the voltage losses in the cables and at the points of connection are low. The difference between the arc voltage and the terminal voltage ought not to exceed 2 V.

The figures quoted for the various arcing time factors indicate the thermal load capacity of the source and, in accordance with ISO recommendations, are based on a cycle duration of 5 min. Thus 60% arcing time factor denotes that the maximum load duration is 178 s plus 2 s short circuit, with 120 s idle. American

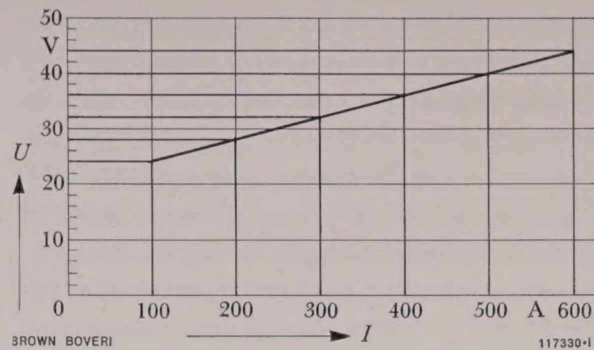


Fig. 1. – Example of a standardized arc voltage as a function of the welding current

U = Working voltage in V
I = Current in A

Although the standards of certain industrialized countries may differ from the above characteristic, they all stipulate a line, either continuous or stepped.

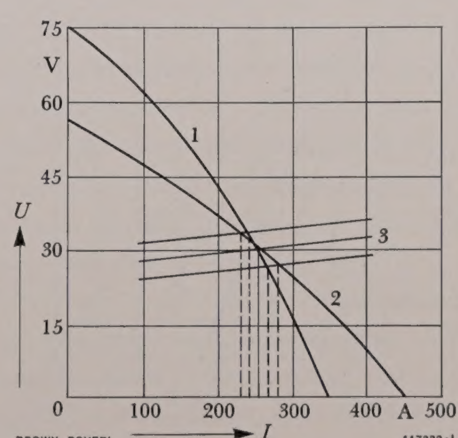


Fig. 2. – Effect on the current of changing the voltage

1 = Relatively steep characteristic } of the current source
2 = Relatively flat characteristic } of the current source
3 = Arc characteristic of the welding electrode

If the characteristic is steeper, a change in voltage results in a smaller change in current than with a flat characteristic.

standards (NEMA) deviate from this rule by basing their figures on a cycle duration of 10 min, while DIN (Germany) stipulate a duration of 2 min and 55% arcing time factor.

Now since the deep-penetration and high-deposit electrodes described result in considerably higher arc voltages, the source supplying the current is also required to operate at a much higher voltage. Normally the sources are capable of producing these elevated voltages, but certain points must be observed when the machine is being set, as will be explained.

The best information regarding the behaviour of a current source is provided by the characteristics (Fig. 2). These curves are statically determined by varying a resistance in the welding circuit between its maximum and minimum values. The values of voltage and current thereby measured are then plotted in the form of a family of characteristic curves. In this manner a characteristic is obtained for each setting of the machine. These curves also show the magnitude of the open-circuit voltage and the steady-state short-circuit current. But primarily they illustrate the variation of the current in terms of the arc voltage, which in turn is determined by the change in length of the arc. The values concerned are therefore static, attained by slow changes.

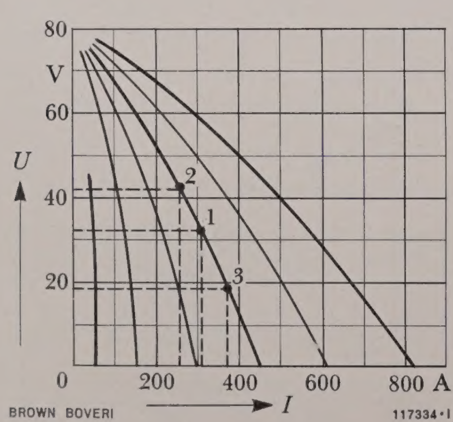


Fig. 3. – Family of static characteristics of a welding converter

Range: from 50 A at 20 V to 500 A at 40 V

1 = Current setting 310 A at 32 V
2 = Working point with longer arc corresponding to higher arc voltage and lower current
3 = Working point with shorter arc corresponding to lower arc voltage and higher current

When welding with deep-penetration and iron-powder electrodes the transfer of material takes place in a kind of spray action without any short circuits. It is thus permissible to speak of almost static phenomena. The dynamic behaviour of the source hardly enters into the matter at all, as it merely influences the ignition of the arc.

If a value has been set on the scale, the machine runs on a definite characteristic (Fig. 3). With stepless control any curve can be obtained between the two extremes. The current which flows finds the desired level in accordance with the arc voltage during the welding process, but the value set on the scale is only obtained when the arc voltage agrees with the calibration voltage. At the higher arc voltages, such as are required for deep-penetration and high-deposit electrodes, the working point wanders upwards on the characteristic, resulting in a reduced current. But in order to obtain the desired current at this voltage, the controls must be adjusted until the characteristic is obtained passing through the point giving the desired current at the elevated voltage. When welding with 4-mm electrodes having a thick covering the setting 200 A may be

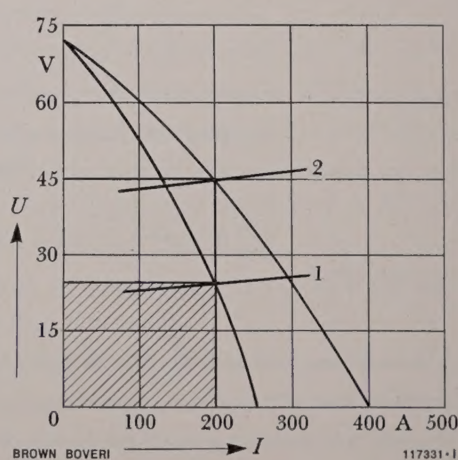


Fig. 4. – Working voltage and power outputs required for different types of electrodes in terms of the characteristic of the current source

1 = Arc characteristic of normal electrodes
2 = Arc characteristic of deep-penetration and iron-powder electrodes

The hatched area represents the power required when welding with normal electrodes and the superimposed rectangle shows the additional power needed when special electrodes are used.

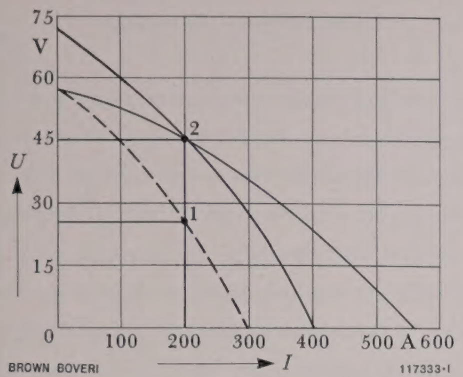


Fig. 5. – Relatively flat and steep characteristics and their influence on welding with normal and special electrodes

1 = Working point with normal electrodes
2 = Working point with special electrodes

chosen, for instance; this current is obtained at 26 V. However, to weld with a deep-penetration electrode 4 mm in diameter, also at 200 A, a voltage of 45 V is required; to obtain this the pointer on the scale must be set to 300 A. On this setting the working point is at 45 V and 200 A, as may be seen in Fig. 4. At this point the power is $45 \times 200 = 9000$ W, compared with $26 \times 200 = 5200$ W. Hence the current source must produce almost double the power required when welding ordinary electrodes having the same core diameter. It is thus evident that, to weld with such electrodes, a powerful supply source must be available, which is capable of producing such an output without harm. On sources which can be recommended for such duties there are usually two scales, one for use with normal electrodes and one for those requiring higher voltage, on which the current needed for the particular type of electrode can be selected.

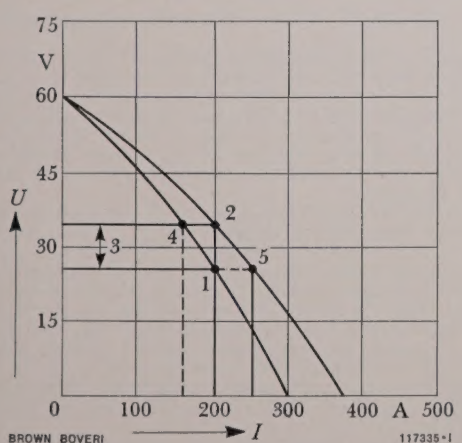


Fig. 6. – Voltage losses in the welding circuit mean that the machine has to produce an increased output

1 = Working point for normal electrodes
2 = Setting needed to cover losses
3 = Voltage increase in the machine to cover losses in the welding circuit
4 = Actual welding current without correction
5 = Current which has to be set on the scale to compensate for voltage losses

But it is necessary to make still another stipulation: When working at such a high voltage there must still be an adequate voltage reserve, in order to obtain as steep a characteristic as possible. Hence a relatively high open-circuit voltage is advisable. Fig. 5 shows a comparison between a source with an open-circuit voltage of 57 V and one with about 72 V. It will be quite obvious that working at high voltages with the machine having the lower open-circuit voltage will give rise to difficulties, whereas with a higher open-circuit voltage it is still possible to draw the arc at elevated voltages.

The Brown Boveri converters rated 500 and 750 A fulfil these severe requirements. The machines types GSMr 500 and 750 are ideal for welding with high-deposit (iron-powder) electrodes.[2] Both these machines have a separate scale on which the current at elevated voltage can be set in such a manner that the correct current is automatically obtained without having to search. The scale is based on mean values of voltages measured on common types of high-deposit electrodes. These machines have always rendered excellent service when welding with deep-penetration and iron-powder electrodes, and have been successfully employed for the manufacture of steelwork and containers, the principal fields in which these electrodes are used.

In this respect it is important to point out another phenomenon which may, possibly, lead to a very heavy and undesired additional load on the current sources. It is well known that cable of sufficiently heavy cross-section should be used for welding, and that care should be taken to keep the contact resistance small at

[2] H. Kocher: New developments in welding converters. Brown Boveri Rev. 1957, Vol. 44, No. 6/7, p. 244–7.

H. Kocher: Brown Boveri welding converters with drooping and flat static characteristics. Brown Boveri Rev. 1958, Vol. 45, No. 4, p. 179–82.

all terminals and soldered joints, as well as at the connections between the earth cable and the workpiece and between the electrode and its holder. But since in many cases the connection between the earth cable and the workpiece in particular is far from perfect, a considerable proportion of the voltage is wasted in overcoming this resistance. Now the electrode itself demands a higher voltage from the machine, in addition to which a further proportion must be provided to overcome these external resistances, as shown in Fig. 6. This increase in the voltage may possibly lead to the source becoming dangerously overloaded. When electrodes are used which require increased power, compared with normal electrodes, it is consequently most important to avoid additional losses of this kind.

Concluding Remarks

When welding with deep-penetration and high-deposit electrodes the sources of current have to meet increased requirements. Not every machine is suitable for welding with such electrodes. Even those machines which comply with the increased demands have to be set to a different working point than used for normal electrodes. Welders should have the physical phenomena explained, because only when they realize what is happening will it be possible to attain optimum efficiency. To keep the losses low it is essential to avoid additional resistance, such as may occur with poor terminals and cable connections.

(KME) W. BUSCH

STATIC CHARACTERISTICS OF THE CURRENT SOURCES AND CONTROL SYSTEMS FOR THE VARIOUS AUTOMATIC ARC WELDING PROCESSES

621.791.75-52:621.311.6

Automatic arc welding, with the various methods available, imposes a wide variety of requirements on the static characteristics of the current sources. When deciding which is the most suitable characteristic it must be borne in mind that it is closely related to the system of controlling the arc of the particular automatic arc welder. Brown Boveri make converters and automatic welders for all kinds of welding processes; the best combinations of static characteristic and arc control system are described in the present article.

THE VARIOUS processes commonly performed with automatic arc welders make different demands on the sources of welding current, particularly as regards their static characteristic. When deciding what characteristic is most suitable for a particular process, though, the system employed for controlling the arc of the welder is very important too. With one system the feed rate of the melting electrode wire is automatically controlled, in such a way that the preset arc voltage is kept constant (voltage control), whereas with the other system the wire is fed into the arc at a constant preset speed (speed control).

For the static characteristics of the current sources a distinction is made between flat and drooping characteristics (Fig. 1). In the latter case the steepness of the curve is quite an important factor; curves may be referred to as not very steep, moderately steep or very steep (Fig. 2).

Submerged-Arc Welding

Nowadays the method known as submerged-arc welding is the most commonly used process for automatic welding. For it mainly a drooping characteristic is required, either with voltage control or constant speed.

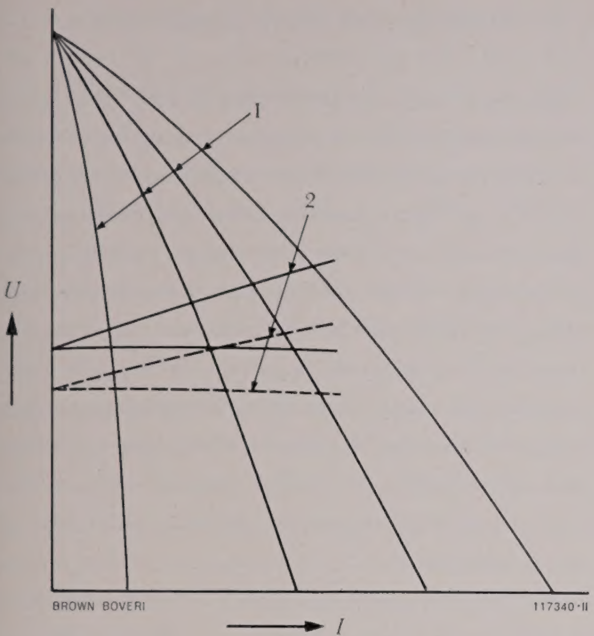


Fig. 1. – Static characteristics of a source of welding current

U = Arc voltage
I = Welding current
1 = Drooping characteristics
2 = Flat and slightly rising characteristics

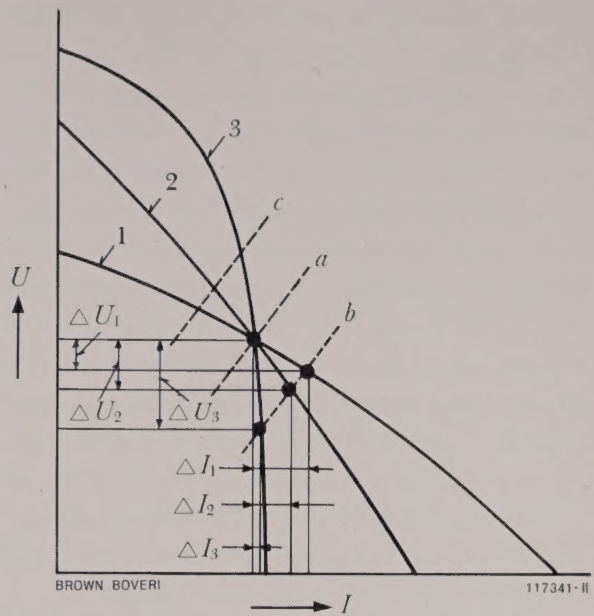


Fig. 2. – Drooping static characteristics of different steepness

U = Arc voltage
I = Welding current
1 = Not very steep } characteristics
2 = Moderately steep } characteristics
3 = Very steep } characteristics

The lines *a, b* and *c* show the relationship between the current and arc voltage at different feed rates of an electrode wire of constant diameter. *b* corresponds to a high speed, *c* to a lower speed. If the speed is set according to line *a*, the current-voltage relationships are the same for all three characteristics. If the feed rate is increased as per line *b*, the welding current changes in the various characteristics by the amounts ΔI_1, ΔI_2 and ΔI_3, while the arc voltage changes by ΔU_1, ΔU_2 or ΔU_3.

The combination of arc voltage control and drooping characteristic is more generally applicable and has therefore been accepted more widely in practice, where excellent results have been obtained, using either alternating or direct current. On d.c. the open-circuit voltages range from 50 to 80 V, on a.c., however, up to 100 V may be used, depending on the kind of flux. Although for submerged-arc welding with d.c. good striking and welding are feasible with a flat characteristic, on a.c. a drooping characteristic is always required because striking the arc and welding are then more dependable owing to the higher voltage. Moreover, in large installations, the voltage drops caused by long cables and heavy currents in the welding circuit do not affect the source so seriously, because here the current does not diminish in proportion to the resistance of the welding cable. Automatic arc voltage control ensures that the preset arc voltage is correctly maintained at all times, thereby rendering the combination largely independent of the steepness of the static characteristic of the current source.

For the combination of drooping characteristic and voltage control the most suitable team-up is an automatic arc welder type E 1200a or E 1200b with a converter type QGS 90s as source of current. With it almost all welding tasks can be performed on plate from about 4 mm thick upwards. For thinner sheet, on the other hand, it is preferable to use the smaller converter type GSMr 750a.

Another known combination is that of a drooping characteristic with speed control. In this case the faculty of the arc for self-regulation is utilized. With this combination, which may be used on either a.c. or d.c., quite large fluctuations in the arc or the welding current must be accepted, depending on the steepness of the

drooping characteristic. These fluctuations are caused by variation of the speed by the wire-feed motor, for example owing to changing load or changes in the distance between the nozzle and the workpiece. The effect of such changes in distance, for travelling welders, is to produce a change in the feed speed of the wire, depending on whether the space increases or decreases. When the characteristic is very steep, such speed changes mainly lead to fluctuation in the arc voltage; with less steep characteristics to current fluctuation (Fig. 2). Hence the most suitable source for such combinations is one whose characteristic is moderately or less steep, because owing to the ability of the arc to regulate itself the fluctuations of both the arc voltage and the welding current are well within limits which still permit good-quality welds to be obtained.

The Brown Boveri automatic arc welder type EV 1000, with constant wire speed, is best supplied from a converter type QGS 90s for submerged-arc welding, because the characteristics of this machine are moderately or less steep, and thus assure good self-regulation.

Submerged-arc welding on d.c. is also possible with a combination of flat characteristic and speed control. But owing to the low open-circuit voltage resulting from the flat characteristic (appr. 25–35 V), difficulties would be experienced in striking the arc. These difficulties, however, can be overcome by making a higher open-circuit voltage available at the instant of striking, which drops to the preset arc voltage as soon as the arc has struck. This combination is primarily suited to the welding of thin sheet with electrodes of small diameter and a high specific loading of the electrode wire because, owing to the flat characteristic of the generator, it is easy to maintain the absolute constancy of the arc voltage which is essential if good-quality welds are to be executed in thin sheet.

As a result of the adequately high open-circuit voltage (50 V) of the converter type GSMr 750u and its adjustable flat characteristic, it fulfils all the requirements for combination with constant speed control [1]. A suitable automatic welder is the type EV 1000, although the types E 1200b or a can also be employed after minor modifications.

Welding with Mesh-Coated Wire

In recent years this process has lost rather a lot of its importance, but it is popular in those cases where the open arc offers advantages for guiding the arc along the seam, or where it would be difficult for the powdered flux to adhere to the edge of the seam with submerged-arc welding. When welding with mesh-coated electrodes, especially where good mechanical properties are required, it is extremely important for the preset arc voltage to be closely maintained, in the interest of the quality of the weld. Therefore the best combination in this case is a drooping characteristic and accurate arc voltage control. Consequently only this combination is met in practice.

For this the automatic welders types U 1200 and E 1200b are employed, the voltage control of which is extremely precise, and they are fed from a converter type QGS 90s.

A flat characteristic and constant feed speed would also afford a sufficiently good guarantee for maintenance of the arc voltage. But owing to the weld metal being deposited in large globules, and the constantly recurring short circuits in the arc, this leads to very unsteady welding with severe fluctuation in the welding current. For this reason this combination cannot be recommended.

Gas-Shielded Welding

For automatic gas-shielded welding the most common processes at present in use in Europe are:

Bare wire and an inert gas, known as metal inert-gas or MIG welding [2]

Bare wire with CO_2, known as CO_2 welding

Flux-cored (folded) electrode with CO_2 (Arcosarc welding)

Of these three methods MIG welding makes the heaviest demands on the current source. The main feature of this method is the very heavy specific load on the electrode wire, necessitating high feed speeds. To

illustrate the conditions which the source has to fulfil, Fig. 3 shows the arc characteristics for a 1·6 mm diameter wire. These characteristics are purely physical properties of the arc, and are quite independent of the design of the current source. Practical experience has shown that, in the event of current changes, greater value is placed on maintaining the length of the arc than on constant arc voltage. This requirement, however, can only be reasonably well fulfilled when the static characteristics of the current source are adapted as closely as possible to the arc characteristic. Owing to the very high specific loading of the wire with MIG welding, the distance between the nozzle and the workpiece, i.e. the free wire length, plays a very important part in the production of a regular seam. The variation in the welding data caused by changing the free wire length can be seen clearly in Fig. 4. The reason for these changes is the fact that the wire becomes incandescent before it enters the arc when the nozzle is too far from the workpiece. Since the maximum permissible length of free wire is 20–25 mm, in the event of the wire feed breaking down, the arc burns back into the nozzle when fed from a source with a drooping characteristic, thereby burning the wire and its guide. In order to minimize this risk of burn-back, the static characteristic of the current source must be made to match the arc characteristic as nearly as possible (Fig. 3). The ideal, slightly rising curve, however, exhibits the disadvantage of a relatively low open-circuit voltage of 15–20 V, which makes it very difficult to strike the arc. To ensure reliable striking, the open-circuit voltage needs to be raised to about 45–50 V, dropping back to the set value of the arc voltage immediately the arc has struck. If a current source possessing the ideal characteristics described is operating together with an automatic welder controlled to constant feed speed, a very effective and simple combination is created for the control. The current is controlled on the welder by the feed rate while the voltage is set on the current source. Since the welding current is only determined by the feed rate and, with the ideal characteristics, the length of the arc remains constant regardless of the current, it is possible to cover a much wider working range by varying the feed rate alone, without having to make

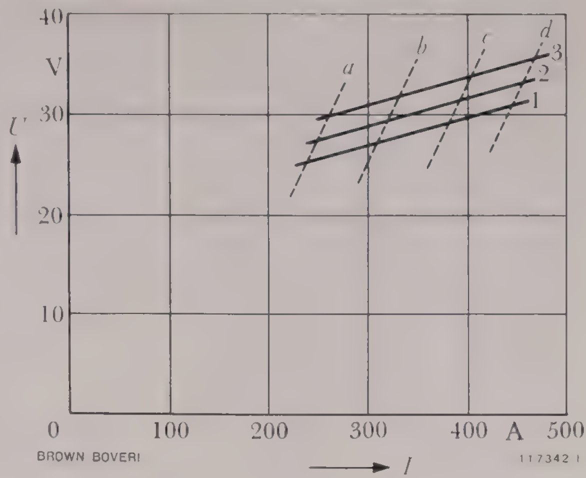


Fig. 3. – Arc characteristics for MIG welding of steel

Wire 1·6 mm in diameter, free wire length kept constant. Shielding gas: argon + 3 % oxygen.

The lines 1, 2 and 3 are arc characteristics for the constant arc lengths 5, 7 and 9 mm. Lines *a*, *b*, *c* and *d* show the current-voltage relationship at wire feed rates of 3, 4, 5 and 6 m/min.

any adjustments to the current source. Every deviation by the static characteristic from that of the arc on changing the current necessitates a readjustment on the current source; the greater the deviation between the two characteristics, the greater the readjustment re-

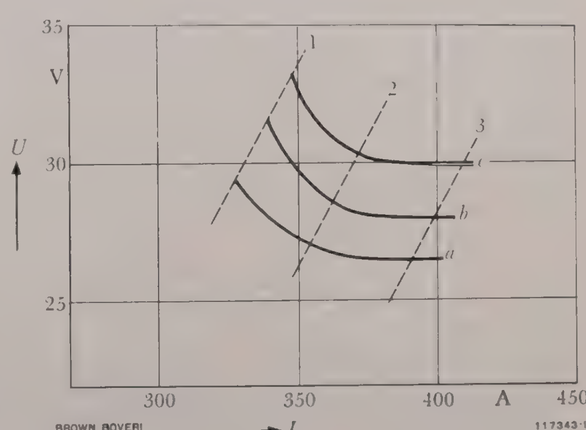


Fig. 4. – Current-voltage curves of the arc for various distances between nozzle and workpiece for MIG welding of steel

Diameter of wire 1·6 mm, constant feed rate, shielding gas: argon + 3 % oxygen.

The curves 1, 2 and 3 represent free wire lengths of 25, 20 and 10 mm. The lines *a*, *b* and *c* are arc characteristics at the constant arc lengths 5, 7 and 9 mm.

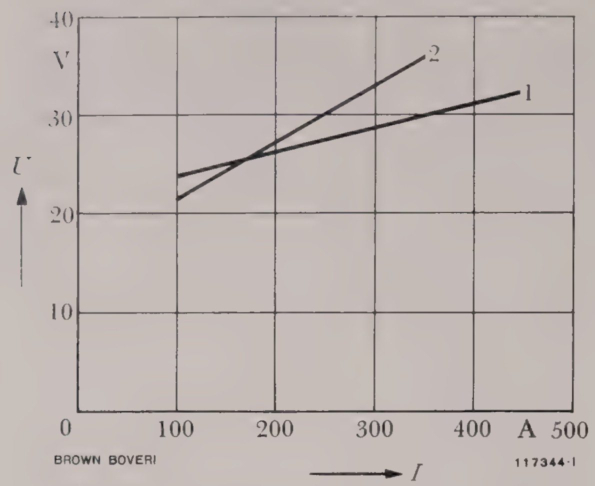


Fig. 5. – Arc characteristics for MIG welding of steel and aluminium

1: MIG welding of steel with A + 3% O_2
2: MIG welding of aluminium with pure A

These characteristics conform approximately to those most commonly employed in practice.

quired. Since the steepness of the arc characteristics is different when MIG welding steel and aluminium (Fig. 5), the source should provide facilities for selecting characteristics of different gradient.

In order to keep the current fluctuations as small as possible when a rising characteristic is combined with constant feed rate, the automatic welder must be able to adhere accurately to the preset speed. Uniform MIG welds of satisfactory quality can only be obtained if this condition is fulfilled.

CO_2 welding poses much less severe conditions on the current source as regards their static characteristics. This is mainly due to the fact that the risk of burn-back into the nozzle is much less than with MIG welding, owing to the weaker ionization of the arc zone in the presence of CO_2 gas. In practice successful results have been obtained with combinations of either flat or drooping characteristics with constant feed rate, or drooping characteristic with constant voltage.

When welding with flux-cored electrode (Arcosarc) the classic system of arc voltage control with drooping characteristic has given very good results and has now become the accepted method. The reason for this is the considerably lower specific load on the electrode compared with MIG welding. In consequence the wire feed rates are on the average only slightly higher than the maximum figures normal with submerged-arc welding. In principle it is also possible to weld with automatic welders having constant feed rate too. In this case, however, it is essential to use a current source having a flat characteristic, in order to minimize fluctuation of the arc voltage caused by changes in the speed of the wire feed motor. The Arcosarc process is very sensitive to changes in the arc voltage.

The Brown Boveri converter type GSMr 750u (Fig. 6) was specially developed with regard to the requirements of gas-shielded welding processes. As a result of the facilities provided for selection of static characteristics varying from drooping to rising, this source is able to fulfil practically all requirements of the

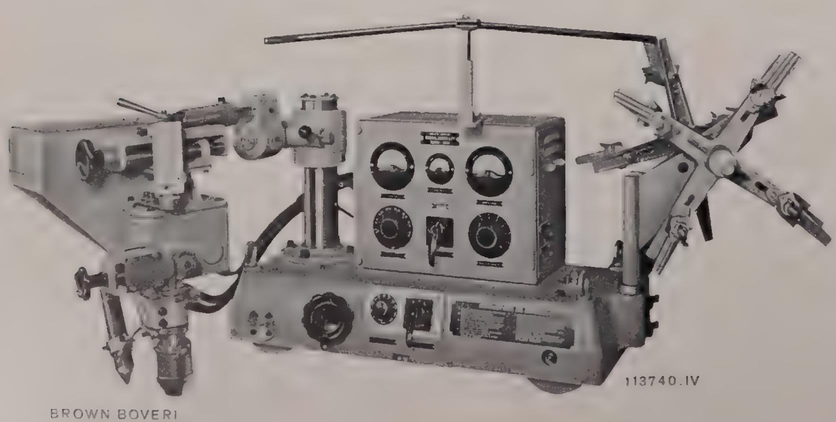


Fig. 7. – Automatic arc welder type E 1200b

This welder can be used for single or twin-wire submerged-arc welding and is equipped with arc voltage control.

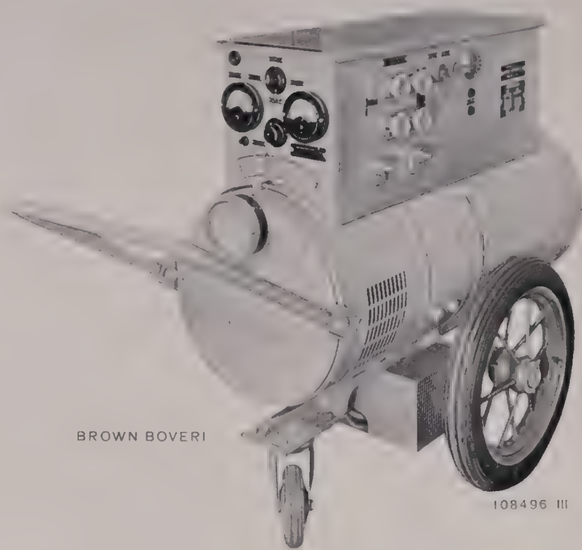


Fig. 6. – Welding converter type GSMr 750u

By means of simple rotary switches the characteristic of this converter can be varied from drooping to flat or even slightly rising.

various gas-shielded welding processes. In addition to this, the open-circuit voltage of 50 V eases striking the arc, particularly for CO_2 welding and MIG welding of aluminium. The automatic welders types E 1200a and b (Fig. 7) can, if necessary, be supplemented to provide the high feed rate required for gas-shielded welding, and constant feed rate.

Brown Boveri automatic arc welders and welding converters equipped with the different systems of control

Welding process		Control		Most suitable combination	
		Arc control (welder)	Static characteristic (converter)	Autom. welders types	Converters types
Submerged-arc welding		voltage control	drooping	E 1200a E 1200b	QGS 90s GSMr 750a
		constant feed rate	drooping	EV 1000	QGS 90s
		constant feed rate	flat	EV 1000 E 1200a E 1200b [1]	GSMr 750u
Mesh-coated wire		voltage control	drooping	U 1200 E 1200b	QGS 90s
Gas-shielded welding	MIG	constant feed rate	rising	E 1200a E 1200b [2]	GSMr 750u
	CO_2	constant feed rate	flat to slightly rising [3]	E 1200a E 1200b [2]	GSMr 750u
		voltage control	drooping	E 1200a E 1200b [2]	GSMr 750a
	Arcosarc	voltage control	drooping	E 1200a E 1200b [2]	QGS 90s GSMr 750a
		constant feed rate	flat	EV 1000 [2]	GSMr 750u

[1] With slight modifications to the circuit [2] Augmented for gas-shielded welding [3] Drooping also possible

To enable the most suitable combination of automatic arc welder and current source to be found for a particular kind of task, the various available possibilities are summarized in the table overleaf.

(KME) H. GÖTZ

Bibliography

[1] H. KOCHER: Brown Boveri welding converters with drooping and flat static characteristics. Brown Boveri Rev. 1958, Vol. 45, No. 4, p. 179–82.

[2] A. SCHMID: Shielded-arc welding with argon and tungsten electrode. Brown Boveri Rev. 1959, Vol. 46, No. 3, p. 210–20.

MULTI-PURPOSE AUTOMATIC ARC WELDERS FOR RESEARCH AND PRODUCTION

621.791.75-52

The wide variety of modern welding processes, especially those which are suitable for automatic execution, necessitate the provision of increasingly extensive and complex electrical and mechanical equipment in order to fulfil all practical requirements. Large firms, where welding is extensively employed, are finding it increasingly necessary to investigate the optimum methods for the application of welding equipment by preparatory work in a welding laboratory or test workshop. This, for instance, is the case at Sulzer Bros., Winterthur, where the welding equipment described is in operation.

ONLY when the electrical welding equipment is employed in conjunction with well-designed mechanical equipment does it become possible for modern automatic welding processes to develop their full efficiency. But in order to employ these economically in a production line, it is essential to have not only good technical facilities, but also an effective shop organization which allows full advantage to be taken of the means available. For instance, it has proved extremely useful to create a special welding section, whose duties are as follows:

The development of new welding processes
Introduction of these processes into production
Instruction of supervisors and welders
Supervision of manufacture
Quality control

The main idea behind the activity of this section is, from the figures and knowledge gained by laboratory experiments, to introduce new applications direct into production, as far as possible utilizing the same machines and equipment, to analyse correctly the experience gained in practice, and to evaluate it so as to achieve improved quality which is the constant aim.

With the present wide choice of different welding processes it is only natural that facilities must be provided for carrying out experiments with all methods of welding using electrodes and gas, including the new methods with various shielding gases. The planned application of certain new metals, in particular titanium and zirconium, demands the provision of equipment enabling the welding process to be executed in a protective atmosphere of extremely high purity, completely excluding air. With the present state of the art it is not yet possible to perform work of this kind on a large scale in any other way than by hand. For the automatic welding of steel the main method today is still submerged-arc welding, while for non-ferrous metals and stainless steels gas-shielded welding is used, with local shielding of the arc zone.

The numerous kinds of applications make severe demands on the versatility of the equipment employed, if it is to serve the various processes as rationally as possible.

Within the scope of this article a description will now be given of two multi-purpose welding installations, interesting from two different aspects, whose conception and constructive design meet the requirements dealt

with above; that is, while mechanically different owing to the dissimilarity in the purpose they serve, they employ the same equipment for a number of different welding processes, great stress being laid on the ability to change from one process to another without undue trouble. This requirement was fulfilled by the versatility of the Brown Boveri welding heads and their control system, as well as by employing a well-planned arrangement of all constructional and control elements. This installation, which was intended for regular production work, was designed as a welding boom (carrying the automatic arc welder) in the one case, while for the other, which had to meet the requirements of a welding laboratory, the mechanical equipment took the form of a self-propelled carriage. In both cases the electrical equipment is basically the same, comprising welding heads and control gear, permitting the execution of the following processes and variants:

Submerged-arc welding with one head, with one or two wires (single or twin-wire welding)

Submerged-arc welding with two heads arranged in tandem

Submerged-arc welding with two heads in series (known as series-arc welding)

Gas-shielded welding (MIG), using argon

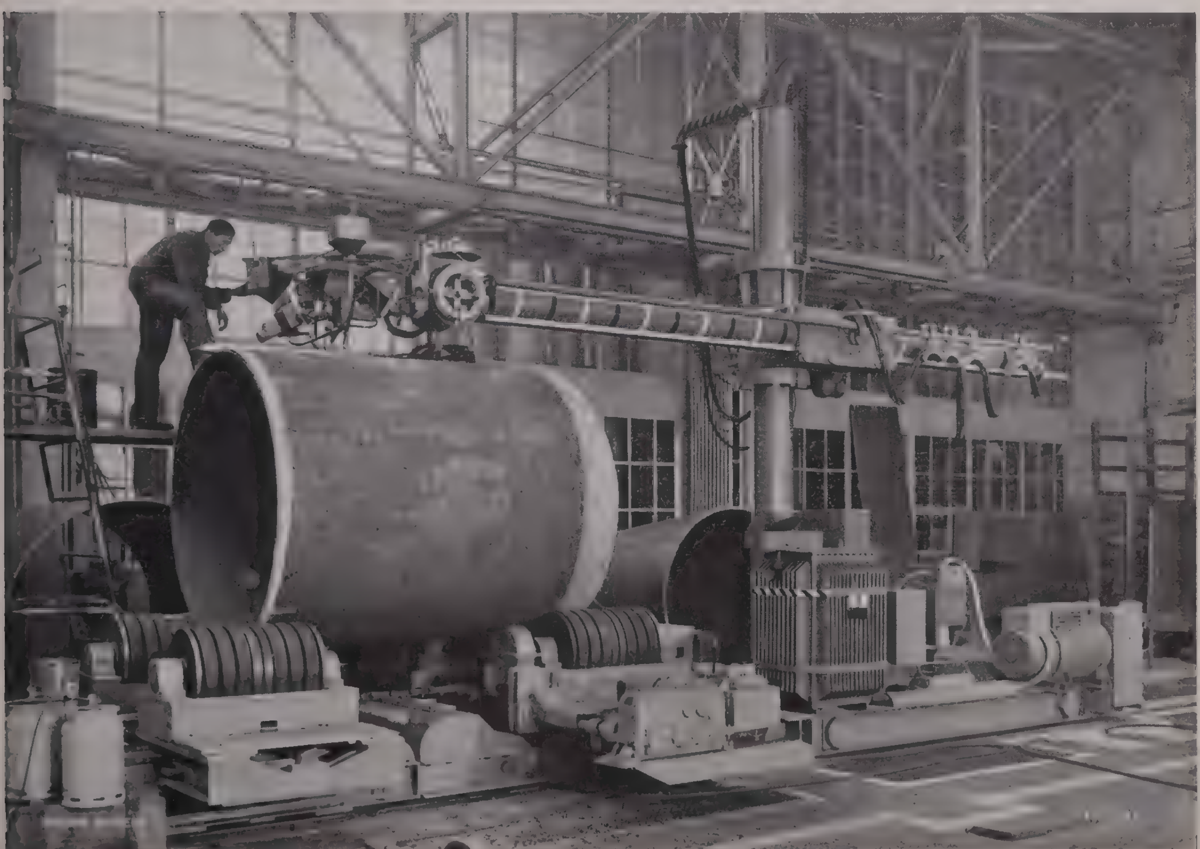


Fig. 1. – Automatic welding installation for the manufacture of heavy machinery and containers

The welding equipment of this installation allows a number of different welding processes to be employed, notable among which are tandem welding for very thick plates and series-arc welding for surfacing. In the picture above, the two welding heads are set for the former process. The heads can be supplied with either a.c. or d.c., in the latter case with either polarity. Instruments and remote control of the current carried by each head allow the installation to adhere precisely to the strict working conditions.

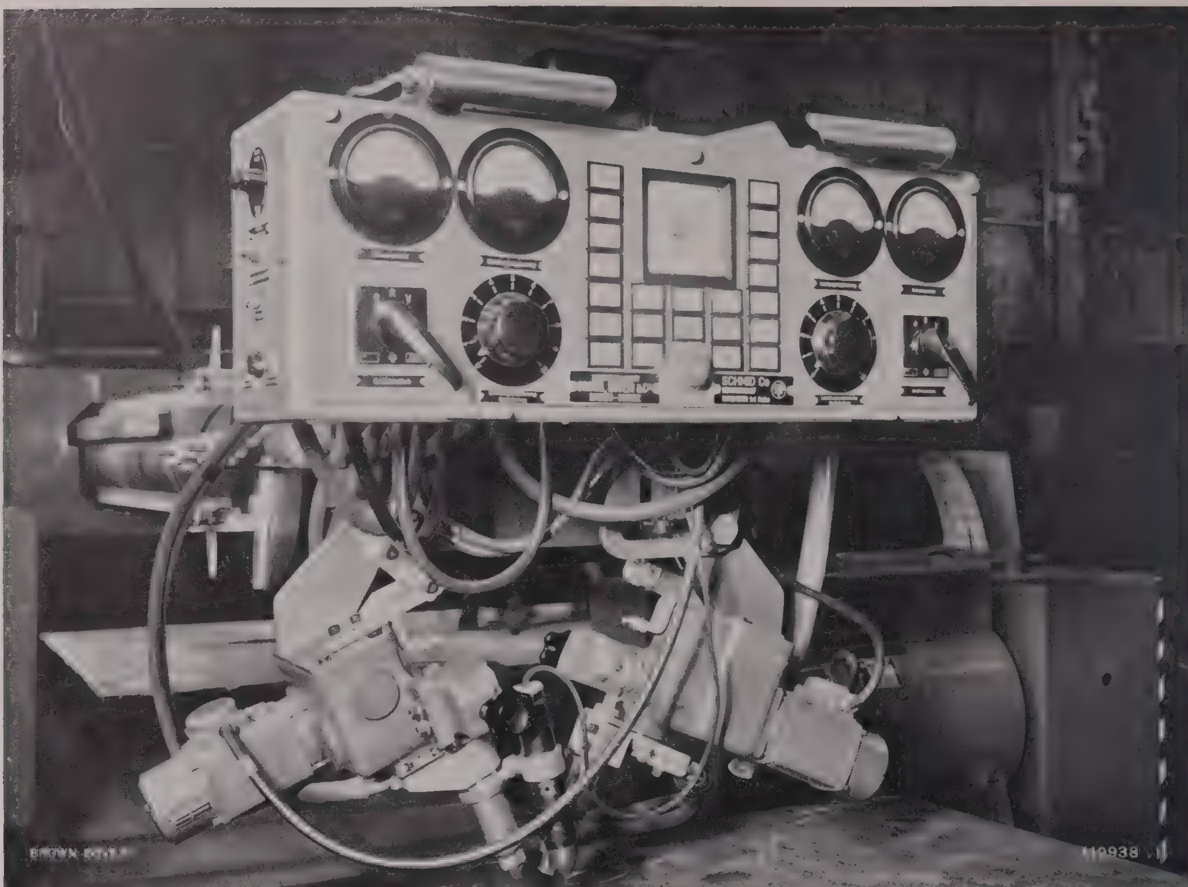


Fig. 2. – Control unit used for operating the two welding heads

The instrumentation includes ammeters and voltmeters in the two welding circuits, as well as a speed indicator. Switches and resistors controlling the feed rate, and push-buttons for the various movements of the welding boom complete the equipment. In this case the two heads are positioned for series-arc welding.

Gas-shielded welding, using CO_2

Gas-shielded welding, using a tungsten electrode in argon and additional filler wire (TIG welding).

Fig. 1[1] provides a clear picture of the constructional layout of the installation and its arrangement in a boiler-makers' shop. Conforming to normal design practice for welding booms, the heads are situated with the control gear immediately concerned at the end of the projecting boom. The vertical pillar supporting this boom stands on a movable undercarriage which also carries the power source and a central control desk. The height of the boom can be varied by up to 4 m and it can be swung round the pillar by 360°. A locking device is provided to hold the boom firmly in any desired position. All movements for the preparation and execution of a weld are power-operated by electric motors, with the following values and ranges:

Longitudinal travel of the carriage on rails, at the same time the welding speed on workpieces mounted parallel to the rails, obtained by a variable-speed d.c. motor:

8–180 cm/min, with a high-speed traverse of 2·5 m/min

[1] Fig. 1, 4, 5, 6 and 7 are reproduced by courtesy of Sulzer Bros., Winterthur.

Transverse movement of the boom, at the same time the welding speed on workpieces with the seam perpendicular to the rails, or at an angle, also obtained by a variable-speed d.c. motor:

8–180 cm/min, with a high-speed traverse of 2·5 m/min

Vertical movement up the pillar for adjustment to workpieces of different height, obtained by a pole-changing three-phase motor:

24 and 48 cm/min

All commands for these movements can be given from the control desk mentioned above. To simplify the task of the welder when adjusting the position of the welding head, the corresponding push-buttons are duplicated on the control unit for the welding heads (Fig. 2). The middle section of the front panel is occupied by the push-buttons controlling the mechanical equipment and a speed indicator which can be set to show the speed of any of the above movements. These elements are flanked on either side by the switches, instruments and control resistors for the two welding heads. The two heads required for the execution of the various welding processes listed above are mounted on a common suspension which allows the heads to be pivoted and adjusted separately or jointly (Fig. 3).

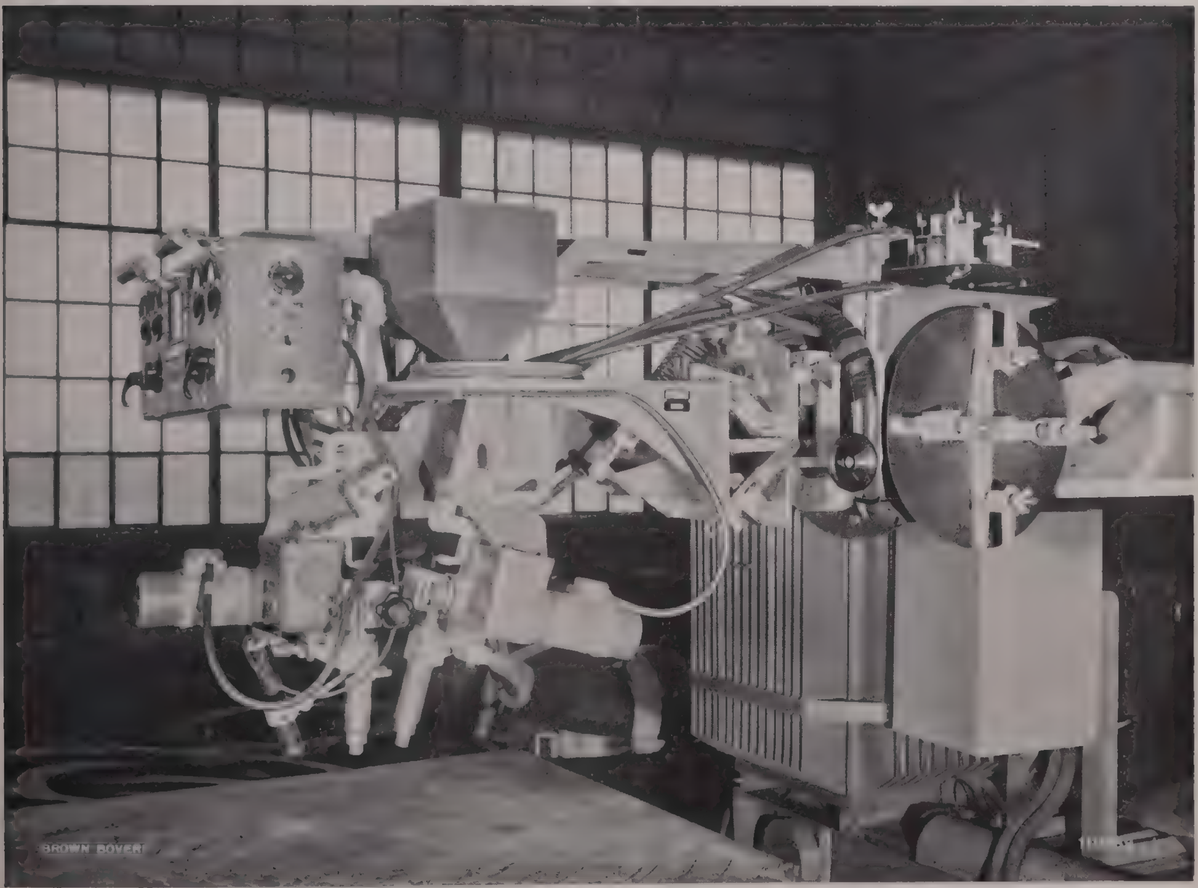


Fig. 3. – Supporting and slewing system for the two welding heads and the control unit

Apart from being able to adjust each nozzle separately, the two heads can be jointly rotated through 90° to stand either in line with or across the seam, depending on which process is employed. In the above picture they are positioned for tandem welding in line with the boom. An optical direction indicator, of the kind normally used for submerged-arc welding, is also very useful here.

BROWN BOVERI 115552 .I

Fig. 4. – Macrograph of a single-U joint in 70-mm plate welded with tandem heads

The first run at the root of the weld was executed with one head fed with d.c., using only one wire; the rest of the weld with a number of runs side-by-side and on top of one another, for which both heads were employed. The leading head was fed with d.c., the trailing head with a.c. The heavier the cross-sections which have to be welded, the more pronounced are the advantages of this process—two to three times the deposit compared with single-wire welding.

The incorporation of these automatic welders in the production line of the workshop is so arranged that the workpieces (pressure vessels, penstocks, etc.) are prepared on one side of the track, while the external seams, both longitudinal and peripheral, are welded on the opposite side. Internal welds on such workpieces are performed in line with the track, the boom moving along the axis of the workpiece.

By dividing up the area surrounding the automatic welder into zones where the workpieces are separately prepared and welded, it is possible to take full advantage of the capacity of the welder as it can be kept working almost non-stop. In order to reduce the time spent in setting up and adjusting the equipment as far as possible, only one size of wire is used, on principle, thereby eliminating loss of time due to changing electrodes. Depending on the wall thickness and the shape of the seam, the first run is executed with one head and one wire, while for subsequent runs both heads are in operation; for very thick plates and wide joint openings twin-wire welding is also sometimes used.

For the tandem arrangement with two heads as shown in Fig. 3, the nozzles of the two welding heads are positioned a few centimetres apart in line with the seam to be welded, the rear nozzle being tilted slightly forwards in the direction of travel. The supply to the leading head may be a.c. or d.c., the opposite always being chosen for the trailing head. The two electrode wires, which need not necessarily be carrying the same current, melt in the same pool. Owing to the high rate of deposit per hour which can be attained with this process, i.e. 12–15 kg/h compared with 5–8 kg/h using only one head, it is primarily used for welding large thicknesses.

The increased welding capacity can also be expressed approximately by the welding speed, which for normal multi-run longitudinal seams executed with two heads is of the order of magnitude of 1–1·5 m/min, whereas for single-wire welding using the same size of wire and for the same seam formation it is not usually possible to achieve much more than 0·5 m/min.

Fig. 4 illustrates a macrograph of a single-U butt weld in steel type A 302 B with a thickness of 70 mm, executed with wire 4 mm in diameter using tandem heads.

The geometrical form of single-U seams has been

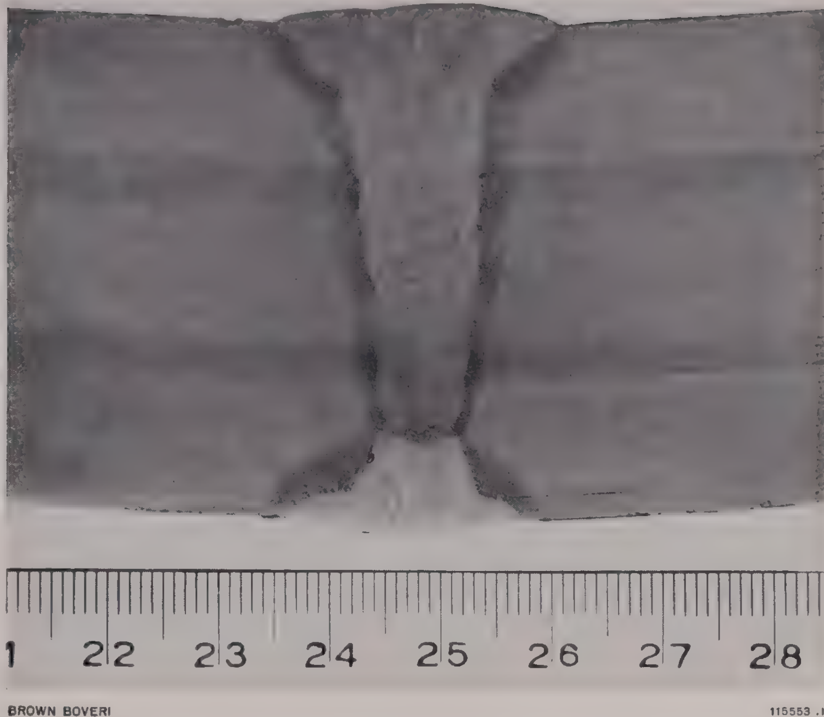


Fig. 5. – Twin-head welding with a reduced seam cross-section brings appreciable advantages because much less weld metal is deposited in a shorter time than required for conventional single-wire welding

The shrinkage perpendicular to the seam is also reduced, an important factor with very voluminous seams.

tested in welding practice for many years and is laid down in a number of welding standards. Skilful execution of the automatic weld allows the width and opening angle of the single-U seam to be reduced, as shown in Fig. 5. This seam was also welded with a 4-mm wire and again for the first two runs only one wire was used, the seam being completed with two heads. This shape of weld may offer quite appreciable advantages, owing to the reduced number of runs and the smaller amount of weld metal which has to be deposited. The entire slot is filled by successive single runs, a double run being used to finish off the seam. With the seam shaped as in Fig. 4 several runs have to be deposited side by side for each layer, with three top runs to finish off.

Twin-head welding in itself permits a considerable expansion of the fields of application of automatic arc welding, but owing to the number of variables—current, voltage, feed rate, wire diameter, angle of the wire, etc.—also increases the number of problems which have to be solved before optimum results are obtained with this process. To thoroughly deal with all these it will probably be necessary to employ mathematical and statistical methods, in order to utilize the values gained by experience of the various tasks.

The strength values of welded seams produced automatically—assuming the same filler materials are used, i. e. wire and flux—can be influenced to quite a considerable extent by the build-up of the seam and the nature of the welding sequence. These possibilities become even more important when welding unalloyed and low-carbon steel with strengths of 55–60 kg/cm^2. The strength can be varied within quite a wide range by the welding sequence, as well as by keeping a check on the inter-run temperature, in addition to a possible post-welding heat treatment.

A further example showing an interesting application of twin-head welding is illustrated by the macrograph in Fig. 6. This is a square-butt joint between two 5-mm plates using a copper backing, welded in a single run. Work of this kind can be executed in material from 3 to 10 mm thick at a welding speed of up to 2 m/min, which is far quicker than the rate attainable with single-wire welding.

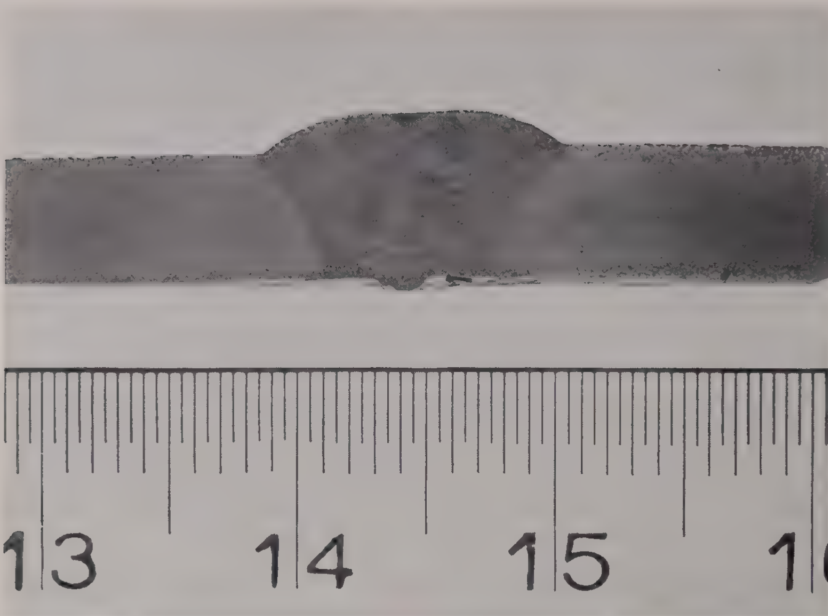


Fig. 6. – Macrograph of a single-run weld in 5-mm thick plate, executed with two heads in tandem

Here too the leading head is fed with d.c., the trailing head with a.c. The high performance of this process is evident, not only with very thick seams, but also with thin plates in the range 3–10 mm thick, particularly owing to the speed of welding in the latter case. Since preliminary bevelling can be eliminated, the stipulations regarding preparation of the material need not be so strict.

In contrast to tandem welding, with its large molten pool and deep penetration, the method known as series-arc welding, i.e. welding with two heads in series electrically, produces very little penetration and is therefore not used for joint welding but merely for surfacing. In this process the parent metal does not form an electrical pole of the welding circuit. The arc is produced between the two electrode wires, inclined at a definite angle to one another. The entire energy in the arc thus goes into melting the two wires, the parent metal being merely melted superficially by the radiated heat of the arc. In spite of the fact that this zone only extends to a depth of 0·4 to 0·8 mm, the deposited material nevertheless fuses reliably to the parent metal. The macrograph of a deposit of 18/8 stainless steel deposited on high-tensile-strength carbon steel (appr. 75 kg/cm^2) illustrates this in a very interesting manner (Fig. 7).

In gas-shielded welding with consumable bare electrode wire (MIG or CO_2 welding) it is well known that the feed rate for the wire is much faster than for submerged-arc welding. Supposing in the latter case the electrode is fed into the arc at the rate of 1·5–3 m/min, a feed system capable of 8–12 m/min must be provided for gas-shielded welding. In the installations under discussion this requirement is fulfilled by replacing one of the heads with a head having a higher gear ratio. This change can be effected easily and rapidly, and is the only manipulation needed when changing from one welding process to the other.

Whereas for submerged-arc welding a control system is employed to keep the arc voltage constant by appropriately influencing the feed rate, with gas-shielded welding this is replaced by a system capable of maintaining the feed rate constant at a preset value. The electrical conditions involved in this process—thin wire with very heavy current densities—result in the arc regulating itself, thus obviating the need for any additional controls. A tumbler switch on the control unit is used to select the particular feed system required.

Conditions are of course quite different with TIG welding using a filler wire. Here one cannot speak of arc regulation because, since the electrode does not move, only an electrically neutral wire has to be fed in at a speed variable to suit the particular requirements. The equipment required for this process (gas torch and wire feed mechanism) is also fitted in exchange for one of the normal welding heads. To simplify matters, the other head attends to the filler wire feed.

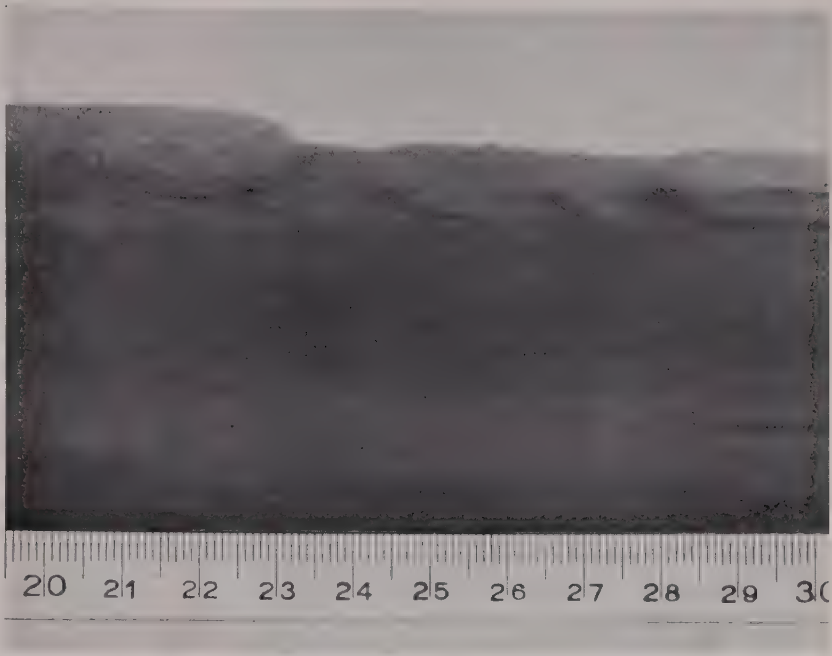


Fig. 7. – Among the welding problems increasingly encountered lately is the application of stainless or heat-resistant material to ordinary steel by surfacing

In this case series-arc welding fulfils the most important requirements—metallurgically sound application due to minimum mixture with parent metal, uniformity and high rate of deposit—and is therefore an ideal aid. The macrograph clearly demonstrates the layer of deposited material and the extremely thin zone of penetration and mixing (about 0·5 mm), the properties of the applied material being already retained in the very first run.

The wide variety of equipment obtainable at relatively little extra expense, and the range of applications on which it can be employed, indicated the desirability and advantages of utilizing the equipment in experimental welding installations, where the conditions for welding and the actual process used are frequently changed. The installation referred to at the beginning of this article and adapted to these requirements is illustrated in Fig. 8 and in the colour plate on the front cover. Here it is obvious at a glance how little space and value the mechanical equipment of this installation represents when compared with that in Fig. 1. The carrier for the welding heads, supported by a small carriage running on the rail, together with the control unit, etc., corresponds to the front end of the boom in Fig. 1. The neat layout and the easy control of the equipment can be clearly seen in the photograph of this installation in action (Fig. 9). The welding pro-

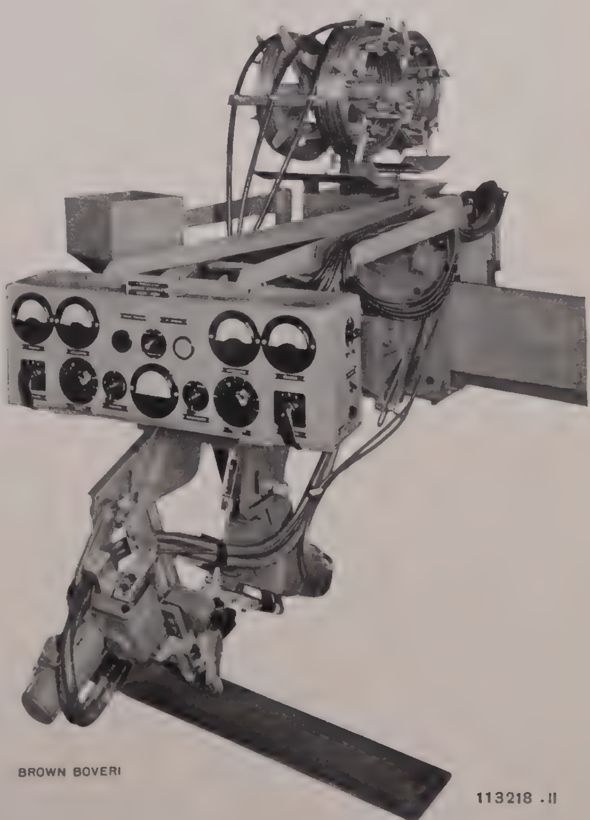


Fig. 8. – Automatic installation for a welding laboratory

This installation, with which preliminary work is often carried out before commencing full-scale production, can perform the same variety of processes as the equipment in Fig. 1. The working range of the automatic arc welder is merely limited by the length of the rail on which it travels. The two welding heads, here in the position for series-arc welding, are supported by a caster which ensures that the nozzles are held at a constant distance from the workpiece.

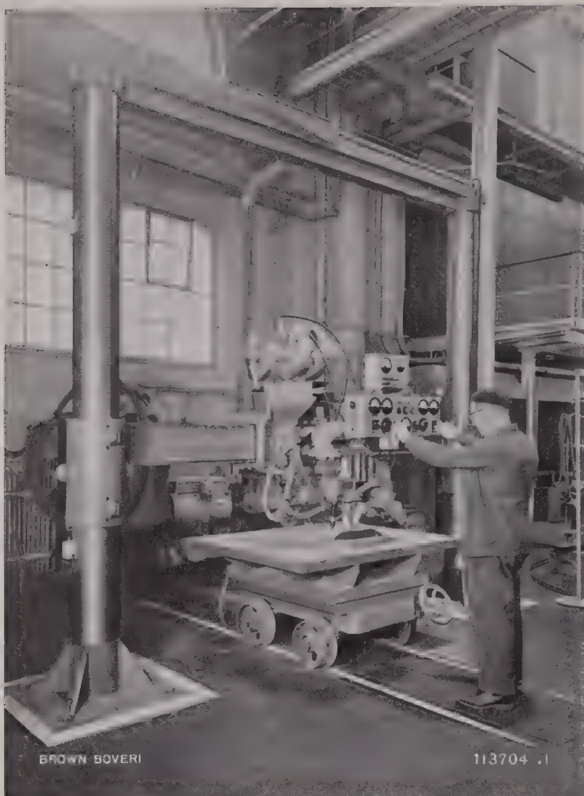


Fig. 9. – Laboratory welding installation at Sulzer Bros., Winterthur

By using a mobile table for the workpiece, it is easy to manipulate the welding head and prepare the test-pieces. The height of the rail on which the welder travels can be varied by a motor, enabling it to work on larger objects. The whole layout of an installation of this kind can be largely adapted to the particular desires or requirements.

cesses which can be executed with this installation are the same as those listed earlier. The rapid and simple changeover from one process to another is particularly appreciated in experimental work, where the tasks may be frequently changed. The choice of the type of current and, for d.c., the polarity, is carried out by means of rotary switches in a separate control cabinet. The two welding heads can be operated with either type of current and with either polarity.

Consequently both d. c. and a. c. sources are provided for both installations, in the form of converters, rectifiers and transformers. Especially for laboratory work a selection of sources is available, having a wide range of properties:

As stationary units a transformer and a converter of normal design with drooping characteristic

Three mobile sources, namely a constant-voltage converter, a rectifier with variable characteristic and a rectifier for TIG welding.

A remote-control system fitted in the control units of both installations is used to vary the current rapidly and steplessly at each welding head, thus permitting the strictest working conditions to be fulfilled.

The results of the experiments performed with the laboratory installation are easily transposed to the production installation, owing to the identity of the electrical equipment. The setting and maintenance of the parameters does not present any further difficulties because the welding operations proceed under at least very similar conditions, owing to the similarity between the electrical performance of the installations, such as the characteristics of the power sources, the principle and the sensitivity of the control systems, and so on. In conclusion it is worth pointing out once more the advantages gained by the technical standard of the equipment, and the purposeful planning of the installations and their employment.

(KME)

A. SMARCAN
G. GERBER (Sulzer Bros., Winterthur)

AUTOMATIC WELDING IN THE MANUFACTURE OF CONTAINERS

621.791.75-52:621.642

Submerged-arc welding by automatic machines is widely employed in the manufacture of containers. The present article refers to the main sections of this field and gives some practical hints regarding the layout of the installations and the execution of the welds.

LARGE containers for the transport and storage of gases and liquids at moderate or high pressure, as well as small vessels for household purposes, are growing steadily in importance. The individual sections are welded together by means of longitudinal and peripheral welds. In the execution of welds of this kind, automatic arc welders attain such a high performance that they have long since overtaken the other methods (oxy-acetylene and manual arc welding).

Automatic welding, particularly with submerged arc, has reached such a high state of perfection that many tasks can be performed, regardless of the shape and thickness of the plate, the nature of the material or the welding programme to be executed. In the process an important role is played by the machines used to control the welding parameters. Welding sheet less than 3 mm thick remains exclusively the task of automatic welders with extremely rapid and accurate control of the wire feed, because here the parameters cannot tolerate the least deviation from the desired values. The slightest change would give rise to flaws, the seriousness of which would be all the more pronounced, the thinner the sheets being welded.

The present article describes some applications of automatic submerged-arc welding performed with Brown Boveri arc welders. These tasks may be divided into three categories:

- Welding thin-walled containers (metal thickness less than 4 mm)
- Welding containers of moderately thick plate (4–8 mm)
- Welding large, thick-walled containers.

Welding Small Containers or Cylinders of Thin Sheet

At present the thinnest sheets which can be welded industrially by arc welding are 1·2 to 1·5 mm thick. Such sheets can be welded with a submerged arc, but only when an automatic welder with very precise and rapid control of the wire feed is used, because a change in the welding current of only 10 A would result in flaws, such as pores, holes or poor appearance, possibly rendering the process useless. Owing to the excellent control facilities of the Brown Boveri automatic arc welders, based on a Ward-Leonard circuit, they have achieved complete success, particularly in this sphere.

With such extremely thin sheets, not only the extraordinary properties of the automatic welders play an important role, but, in addition to the quality of the material, the accuracy of the manipulators and jigs used. A few examples will be studied by way of explanation.

Longitudinal Seams in Container Bodies of 1·5–2-mm Sheet

Welds of this kind are performed on a clamping device equipped with a copper bar. A slot, usually milled in the bar, acts as a mould for the molten metal and determines the volume of the welding run, pro-

vided due allowance is made for the welding parameters. The part to be welded must be held very firmly on the copper bar. Even the least error in the position may lead to irregularities in the weld or to a shortage of metal at the surface. Perfect positioning is generally obtained on manipulators where the copper bar is fastened by pneumatic lifters. If the joint is properly aligned with the slot in the copper backing, the lifters, located about 15 cm apart, can be put under pressure, thereby pressing the backing and the joint together on to the fixed part of the manipulator (Fig. 1 and 2).

The copper bar must be water-cooled, but the cooling must not be too intensive as this would lead to the seam being cooled too rapidly, with the risk of hardening and formation of cracks. Generally the cooling circuit runs once in each direction beneath the copper bar.

This bar should be roughly 40–50 mm wide and 12–15 mm thick. Table I below gives some approximate figures for welding.

TABLE I

Thickness of sheet mm	Welding current A	Welding voltage V	Welding speed cm/min
1·5	210	24	120
2	280	27	100
2·5	350	28	100

Fig. 3 depicts an installation for welding the containers of fire-extinguishers.

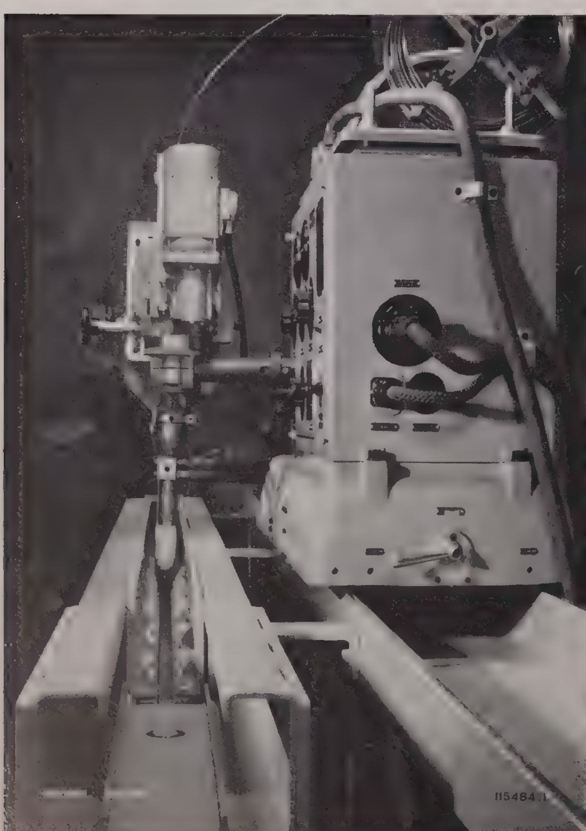


Fig. 1. – Clamping device for longitudinal seams on hot-water tanks for household systems

The sheet can be 2·5–3 mm thick; it is welded on a copper backing.

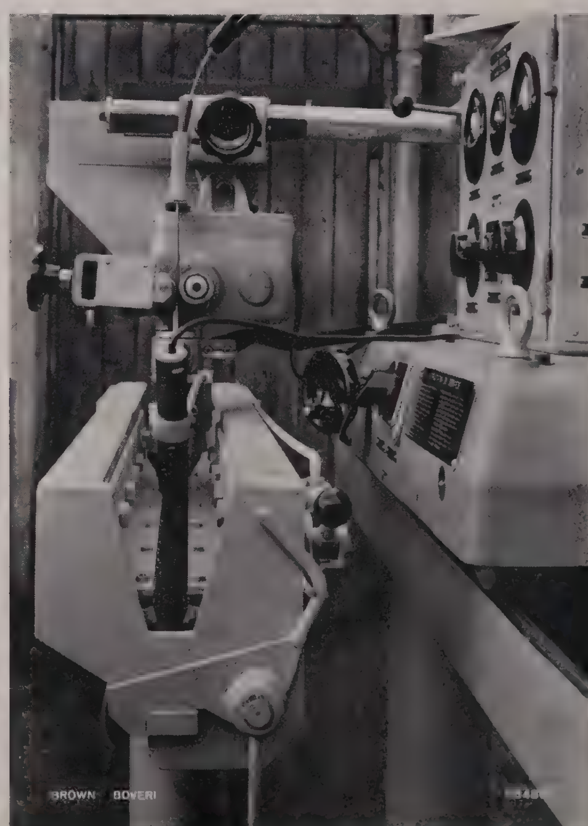


Fig. 2. – Clamping device for longitudinal seams on fire-extinguishers

The sheet is 1·5–2 mm thick; it is welded on a copper backing.

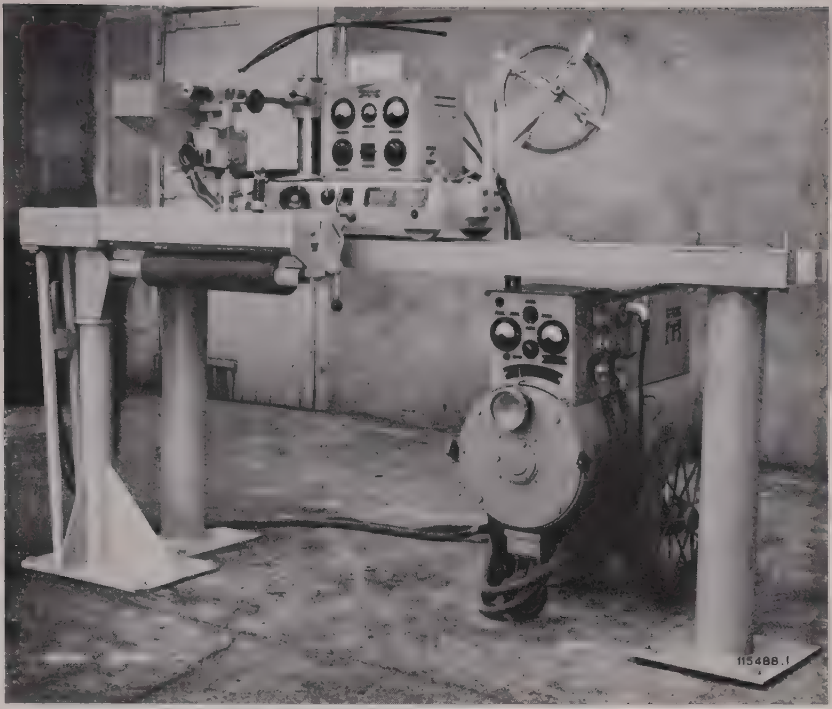


Fig. 3. – View of an installation for welding longitudinal seams on fire-extinguisher containers

Data as for Fig. 2.

The nature of the parent material has a decisive effect on the result. The best results at favourable price are obtained with an electrode wire as nearly neutral as possible and containing 0·5% manganese. It is used in conjunction with a flux enriched with manganese because this element exhibits a tendency to prevent cracks and pores, regardless of the composition of the basic metal, i.e. no matter whether it contains sulphur or phosphorus as impurities.

The flux used should be one which gives the molten metal as good an appearance as possible. Intensive research has succeeded in developing fluxes which, when used with ordinary wire, are able to lend the deposited metal very satisfactory mechanical and chemical properties.

Welding Small Containers such as Gas Cylinders

The cylinders used for storing butane gas are one field exclusively reserved for automatic welding, as they are typical mass-produced articles. The employment of a quick-release clamping device and an automatic arc welder with an extremely sensitive control system for the wire feed is usually sufficient to achieve very economical welding, thereby reducing the number of cylinders scrapped during inspection, and keeping the number low all the time.

As will be well known, cylinders of this kind are obliged to pass very strenuous tests. Following heat treatment at 900 °C they are subjected to the normal, systematic test at a pressure of 20 atm. A statistical test to a minimum bursting pressure of 75 atm is also carried out. The latter average value varies according to the specification of the particular classification society. Also measured is the elongation over the full length of the cylinder, including the welded seam; the relevant standard specifications are extremely strict.

In this manufacturing process, for which manual welding has been more or less completely discarded, Brown Boveri automatic arc welders have achieved notable success. In many works there is even a tendency towards replacing existing machines, such as those with constant wire feed, by the considerably more sensitive Brown Boveri types.

Butane cylinders have two welded seams; one is the joint between the two deep-drawn halves (Fig. 4), the

Fig. 4. – Peripheral welding of butane gas cylinders
(Courtesy of Etablissement Fournier, Cavaillon, France)

other the attachment of the connecting nipple to the upper half. There are three possible methods which may be adopted for preparation and welding: butt welding, welding with a backing ring and welding with an overlap, one of the two halves being crimped and pushed inside the other (as in Fig. 5b). For square-butt welding a copper roller is required to support the joint. Before welding starts, this roller has to be inserted in the cylinder. For this a small collapsible holder is used, which is withdrawn through the opening when the weld is finished.

The roller, which has to be cooled, runs on the inside wall of the cylinder, being pressed against it by a spring. This method, ideal in principle, assures uniform welding over the entire length of the seam and eliminates all risk of corrosion; however, considerable difficulty is involved in the preparation, because the roller has to be introduced, exactly positioned and removed after welding. For reasons of economy these auxiliary operations must not be allowed to occupy too much time.

Welding with a backing ring is also waning in popularity (see Fig. 5a). There are two main disadvantages associated with this method. Making and tacking on the ring wastes time, and two possible corrosion zones are produced, these being particularly endangered when an internal lining has to be applied. On the other hand, the backing ring, if it fits well, affords a useful support for the molten metal.

The method generally adopted nowadays is overlap welding as in Fig. 5b. This method not only offers the great advantage of facilitating the fabrication of the cylinder by crimping the end of one half, but this also provides an excellent backing for the molten metal. The preliminary operation can be performed remarkably accurately. But even this method has its drawbacks. The welding parameters have to be adhered to very accurately as there is a pronounced tendency towards cracking in the zone of deformation round the crimp; also on the inside there remains a joint which is exposed to corrosion. The connecting nipple is welded either with overlapping edge or on a copper roller.

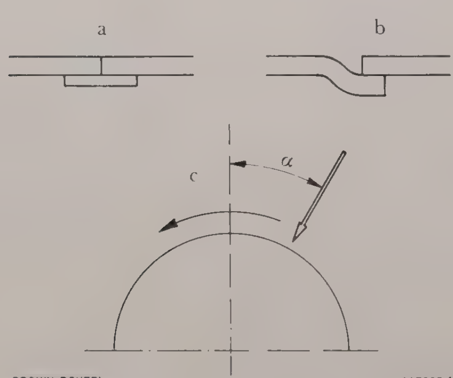


Fig. 5. – Peripheral welds in gas cylinders

a: Section through a square-butt joint with backing strip, before welding.

b: Section through an overlap joint before welding. The edge of one half is crimped and inserted into the other half.

c: The electrode is not situated at the highest point but at an angle α = appr. 20° from the top.

To weld the peripheral seam the cylinders are clamped between a pair of chucks and preferably welded in two runs. For all three methods the welding parameters are roughly equal, namely:

Welding current	I = 300–400 A
Welding voltage	U = 24–26 V
Speed of rotation	c = 1·3–1·8 m/min
Wire diameter	d = 2·5 mm

The angular setting α of the electrode wire exerts a considerable influence on the form of the seam. It is a function of the speed of rotation of the cylinder and the welding values employed. For butane cylinders α is usually in the region of $20°$ (see Fig. 5c).

In order to ensure that the seam is properly welded through over its full length it is preferable to replace the starter switches by contactors and time-lag relays. In this way striking is relieved of the weaknesses of manual operation and the weld time is exactly timed, likewise the time for lifting off the electrode on completion of welding. This eliminates serious flaws. The same equipment can be utilized for other purposes, especially where the advantage of accurate striking proves beneficial.

Welding Containers of Moderately Thick Plate

In general, with plate thicknesses from 4 to 8 mm, square-butt welding is used in order to simplify the preparatory work. A welcome saving can thereby be effected. But it is always necessary to provide a sound backing for the molten weld metal. This backing is obtained in different ways.

Backing Run Applied by Hand from the Underside

The classical method is to apply a backing run from the underside by hand (Fig. 6a). For plate 4–6 mm thick this backing run is executed with ordinary electrodes. These ensure adequate penetration to hold the subsequent runs applied by the machine.

For plates 6–8 mm thick or more it is common practice now to use deep-penetration electrodes. With certain types of these electrodes it is possible to achieve a penetration of up to 4 mm without any special precautions and at quite high speed, the appearance of the resultant seam being very good indeed. This very important initial run is quite strong enough to hold the subsequent machine run, which in turn ensures adequate fusion of the two runs.

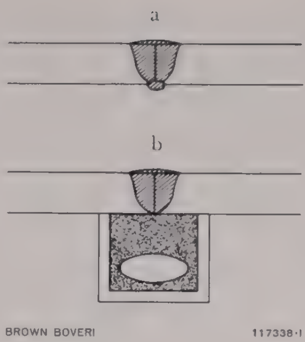


Fig. 6. – Welding containers of moderately thick plate

a: With a root run welded by hand.

b: Welding against a flux backing.

This procedure is the same for both longitudinal and peripheral seams. The quality of the preparatory work plays an important part in determining the welding speed, and thus the economics of the operation; the welding values are governed not so much by the thickness of the plate but, to a considerable extent, by the preparation.

Welding on a Flux Backing

For the moderate plate thicknesses, and particularly for longitudinal seams, it is desirable to dispense with the copper backing. In fact, the pressure needed to ensure reliable contact would be far too high. From this consideration it was logical to proceed to the idea of a softer backing, which adapts itself to the shape of the workpiece, yet at the same time affords very effective protection to the underside of the seam.

This idea was realized by the flux backing, as used for plates up to 6 mm thick. The joint is placed over a channel section, embedded in which is a flexible air chamber with flux on top (Fig. 6b). When the workpiece is correctly positioned over the channel, air is blown into the chamber, thus pressing the flux against the joint on the underside. The result of this is that slag is also formed on the underside of the seam, thus affording complete protection of the seam. Industrial experience with this method has been very satisfactory.

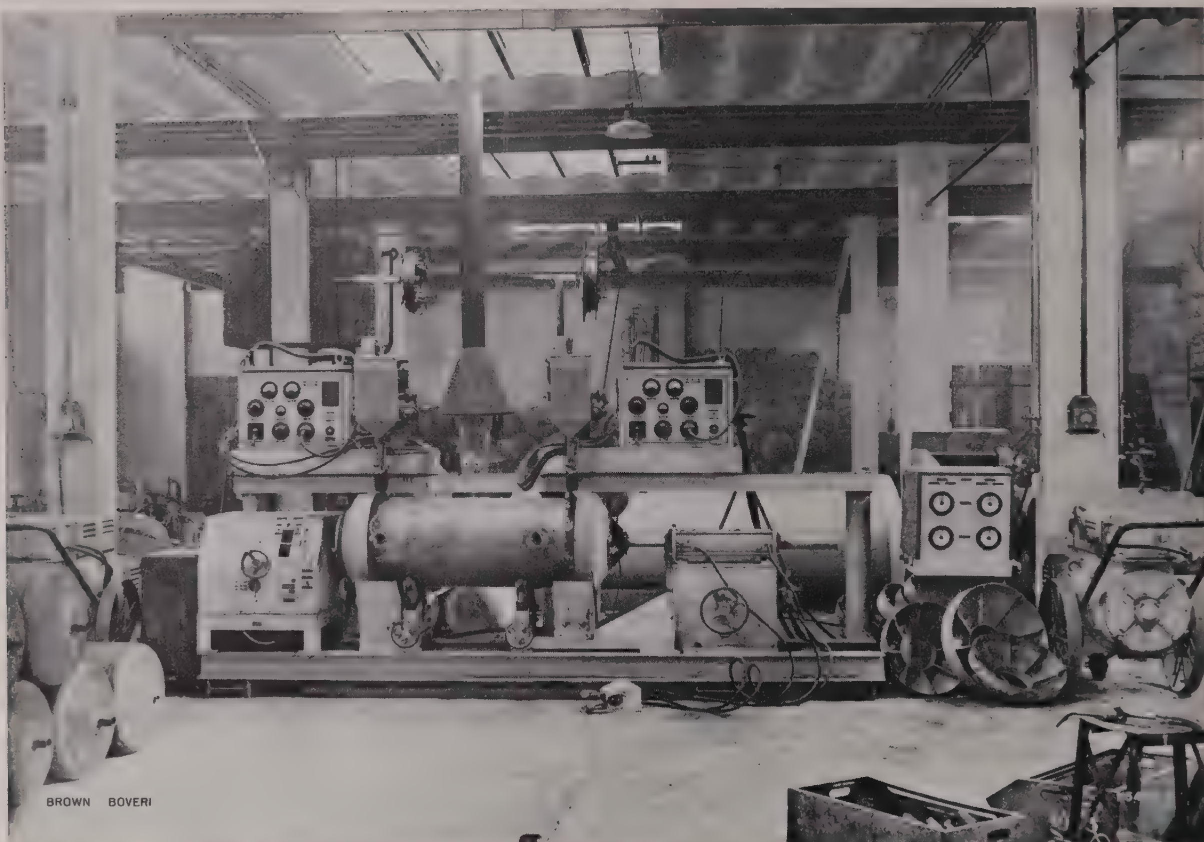


Fig. 7. – Installation on which two peripheral welds are executed simultaneously on water tanks

Of the right of the manipulator is a device controlling the striking action and interruption of the arc after welding; this is done synchronously and automatically for both heads. (Courtesy Etablissement Pauchard, Autun, France)

Use of Manipulators

Decisive for the successful employment of automatic arc welders are the manipulators which are also used. When welding containers of small capacity—for instance, hot-water tanks or storage tanks holding up to about 500 l—it is best to roll in the ends because, except in a few cases, the plate used is rarely above 4–5 mm thick.

If two welding machines are employed it is possible to execute both peripheral seams simultaneously. For this the container is held between chucks similar to those on a lathe (Fig. 7). Naturally this system can be augmented by an automatic control device for striking the arc and stopping the welding process, as was described in the previous section dealing with butane cylinders.

For objects with large capacities the first run is usually applied by hand. In this case the manipulators are more comprehensive. In principle a choice may be made between two different types (Fig. 8 and 9).

Following tacking, the body of the container is placed on a rotary manipulator, on which it is rotated at a preset speed. This manipulator may also be able to travel along rails, thereby permitting the execution of longitudinal welds. The spacing of the supporting rollers is set to suit the diameter of the container. Fig. 10 illustrates the welding of a 12 000-l container as an example. The welding head can be raised into the desired position by a boom or a special crane. In the

Fig. 8. – General view of a workshop welding containers of all sizes

This workshop contains:

3 automatic arc welders type U 1200
3 welding booms
4 rotating manipulators
3 welding converters

(Courtesy Etablissement Pauchard, Autun, France)

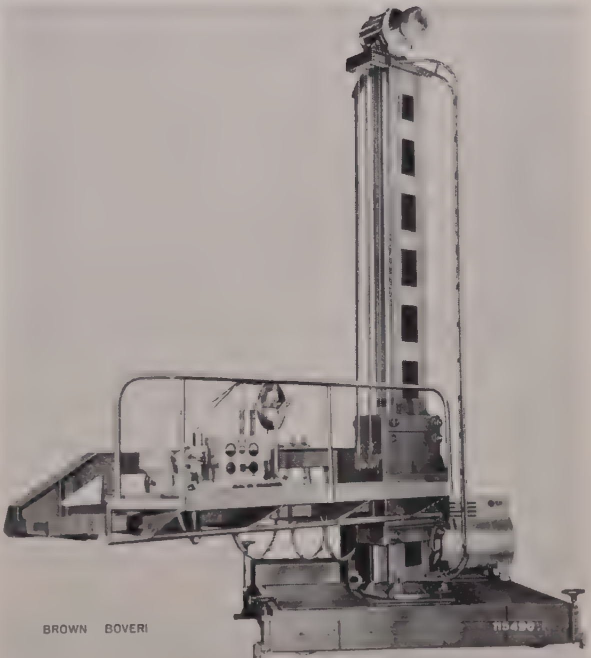


Fig. 9. – Welding boom equipped with an automatic arc welder type E 1200

case of the boom the automatic welder runs on a rail carried by the boom, the height of which is variable on a vertical pillar. This pillar is usually mounted on an undercarriage which can run on the floor or on rails at a preset speed. In this manner it can be used for longitudinal seams. This system, however, is not practicable for the production of small containers as the size of the boom is quite large; in any case such small containers are rarely made from plate 4–8 mm thick.

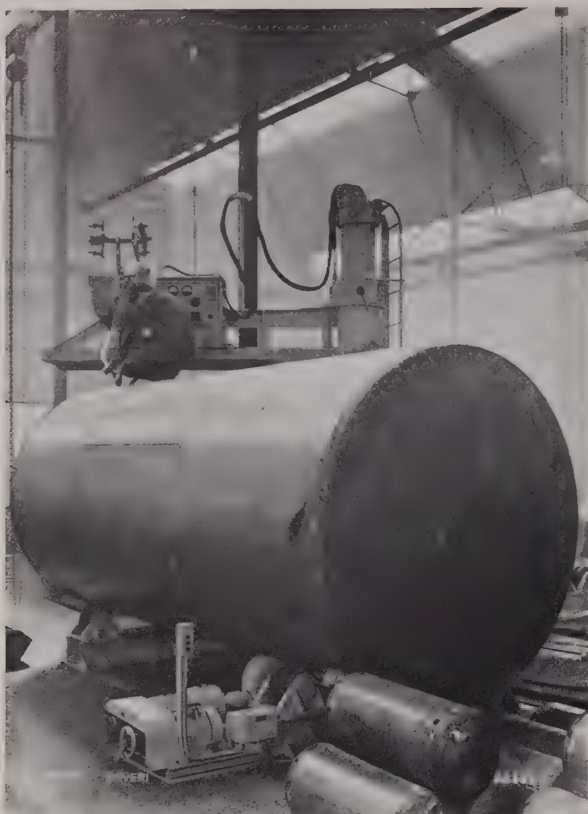


Fig. 10. – Welding a 12000-l container
(Courtesy Etablissement Pauchard, Autun, France)

The welding crane is designed on another principle. It consists of a retractable arm, at the end of which are only the devices for the wire and flux feed. The end of this arm is consequently much smaller and can be inserted into relatively narrow openings in the bodies of cylinders. The controls are mounted elsewhere, either on the carriage of the crane or near the point where the operator stands. The height of the retractable arm can be varied by means of a pillar, as with the boom. The carriage can also be moved on rails, thereby opening a wide field of applications. An installation of this kind is perhaps more versatile than a simple boom, but it is also more expensive.

The Brown Boveri automatic arc welder type E 1200a with controlled arc can be supplied in the form of separate sub-units which are easily adapted to manipulators of the above kind.

Welding Large Containers of Plate over 8 mm Thick

This is another field in which automatic welding is preferred. Filling the joint with the aid of a machine is particularly economical for this operation. Here, too, great importance is attached to the first run, as well as the preparation of the plates. With 20-mm plates the commonest joints are single-V or single-U seams (Fig. 11a), with a root run applied by hand and, possibly, a second run from the underside if necessary. This second run is very useful as it provides a solid foundation for the succeeding automatically applied runs. The first of these can then be applied at a much higher current, thus rendering it unnecessary to reset the values for subsequent runs. Unequal double-V butt joints are, however, also prepared, the smaller part being filled by hand with iron-powder electrodes (Fig. 11b). In all cases in which the seam is subjected to strict tests it is essential to gauge the root after the first run, in order to avoid flaws or inclusions.

For plates more than 20 mm thick the equal double-V butt seam is preferable if welding is possible inside the body of the tank. In this way the volume of weld metal is greatly reduced. In this case two manual runs are applied (one from the outside and one from the inside), filling always taking place with the machine. With very thick plates and from a certain joint width upwards, narrow runs are deposited, the angle of inclination of the nozzle being altered accordingly (Fig. 11c).

Finally, for very thick plates indeed, i.e. over 50 mm thick, single-U welds are preferred throughout. This shape permits the quantity of filler metal which has to be melted down to be appreciably reduced. The two root runs, one from the underside, are welded by hand or by a semi-automatic process. Here too the use of electrodes capable of penetration up to 4–5 mm is economically advantageous. The positioners are of the same kind as those used for moderately thick plates. Of course the rotating devices have to be capable of carrying much heavier loads. Since production is usually on a one-off basis, the manipulators are equipped with a means of adjustment for the supporting rollers, e.g. worm gearing.

Metallurgical problems are, however, also encountered. The weldability of the parent metal is very important. If it is low-alloy steel, it is usually sufficient to combine a special flux with ordinary electrode wire to obtain the desired properties in the weld metal. The post-weld heat treatment has only to take the parent metal into account, provided the weld metal is of the same kind.

Conclusions

Automatic welding is widely employed in the manufacture of containers of all sizes and from all thicknesses of plate. In each case problems arise regarding the preparation, manipulation, the thickness of the material and the metallurgy, which require studying specially. The stipulations which have to be obeyed vary appreciably and lay down certain directives which must be scrupulously adhered to.

Brown Boveri automatic arc welders type E 1200 and U 1200 are ideally suited to the fulfilment of the stipulated functions, owing to their excellent control system. Their outstanding properties for welding thin sheet 1–2 mm thick are generally recognized and do not need specially underlining. But for medium and heavy plate, for which they ensure the maintenance of the selected parameters, the above remarks on the control system also apply. The range of automatic machines is augmented by the type EV 1000 which, owing to its special design, can be used for filling seams of any shape, particularly fillet welds on heavy and medium plate. Thus Brown Boveri are able to offer a complete range of automatic arc welders which cover the entire field of container production. Specially adapted manipulators allow the most to be obtained from the welders, all problems associated with their application being ideally solved with the aid of the wide selection of supplementary materials.

(KME) M. Guérin

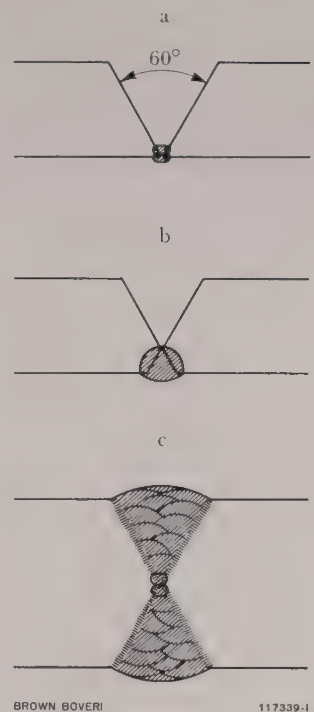


Fig. 11. – Various methods of welding thick plates

a: Single-V seam with two manual runs.

b: Unequal double-V seam with one manual run executed with iron-powder electrodes.

c: Double-V seam with two manual runs followed by automatically applied runs.

MECHANIZED ARC-WELDING TECHNIQUES

621.791.75-52

This article deals with the duties which have to be performed by the operator of a welding machine in addition to supervising the automatic operation of the machine. He must also be able to judge a seam from its appearance and improve its shape during welding by correcting the settings. The basic settings, such as the kind of current, the polarity of the electrode, wire diameter, current density, angle of the wire or workpiece, contact clearance and the earth connection, all affect the shape of the weld to some extent. The welding values and the basic settings together are the values which govern the quality of a weld. Their influence on the form of the seam are described in detail.

Significance of Automatic and Semi-Automatic Welding Installations

TODAY automatic and semi-automatic welding installations can be found in large and small plants in all branches of industry. The choice of the most suitable welding process for a particular task is left to the welding expert, but afterwards the installation is usually operated by semi-skilled men who have passed a course of training. In such courses the operator of a welding machine has to learn about the most important factors in automatic arc welding. Often this is not done, with the result that, when a poor weld is produced, the machine is given the blame in many cases. A mistaken view held by many people is that the machine adjusts the data necessary for good welding of its own accord. This is not the task of the automatic welder; its task is to keep constant those values which were set by the operator. This and its greater welding capacity are the main advantages of the automatic arc welder [1, 2, 3]. The values governing welding, such as the current, voltage and speed, must be preset by the operator and supervised during welding. But to be able to do this, the operator must know what effect they have on the formation of the seam.

Types of Welds and their Designation

In automatic arc welding the types of welds used for joints and surfacing [4] and their nomenclature have been standardized (see Fig. 1). It is of course a primary essential for the parent metal and the filler metal to be correctly matched, if a weld is to be successful.

The strength of the seam depends not only on its composition, but also to a considerable extent on the formation of the weld. This comprises the depth of penetration h_e, the height of the reinforcement h_a and the width of the weld face b. The sum of h_e and h_a is known as the throat thickness h, usually denoted by a for fillet welds. The choice of the most suitable form of weld depends on a number of factors, such as the type of seam and material thickness, the material itself and its quality, the size of the workpiece and the accessibility of the joint, possible preparation of the joint and the severity of acceptance specifications.

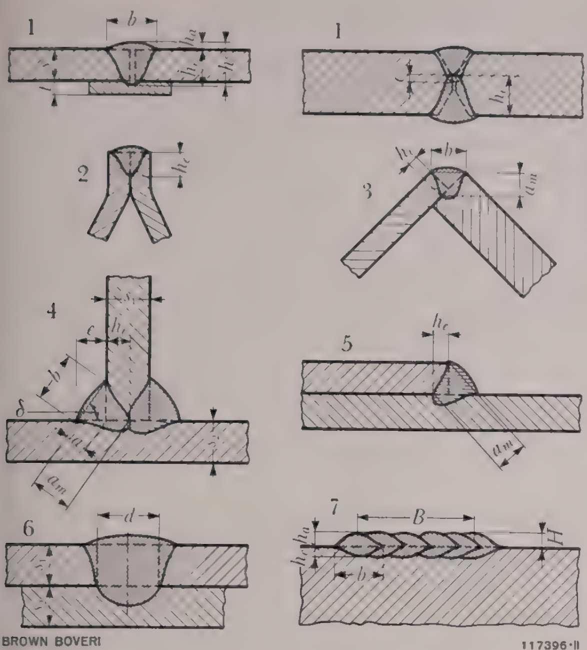
Form Coefficients

Form coefficients of seams provide information regarding the geometrical state of a welded joint [5]. Here it is common practice to distinguish between two values, namely the form coefficient φ_e of the internal and φ_a of the external seam.

For the inside of the seam φ_e is obtained from the ratio of the width of penetration (= the width of the weld face) to the depth of penetration; the external coefficient is given by the ratio of the width of the seam to the height of reinforcement, i.e.

Internal form coefficient (of penetration) $\varphi_e = b / h_e$

External form coefficient (of reinforcement) $\varphi_a = b / h_a$



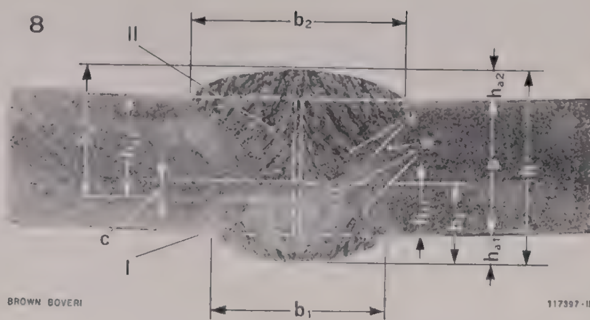


Fig. 1. – Types of welds and their designations

Types of welds:

1 = Square-butt weld welded on one side with backing, and double-V butt weld
2 = Edge weld
3 = Corner weld
4 = Double-bevel butt weld
5 = Overlap weld
6 = Plug weld
7 = Surfacing
8 = Square-butt joint welded by submerged arc from both sides (runs I and II). On application of the top run, the lower run suffered a change in structure (lower conversion point of carbon steel = 721 °C), while the upper run has a pure cast structure.

Designations of form:

a = Throat thickness of a manual fillet weld
a_m = Throat thickness of a machine fillet weld
b = Width of seam
c = Penetration overlap
d = Diameter of hole
e = Projected thickness, as measured
h = Throat thickness of a butt weld
h_a = Reinforcement
h_e = Depth of penetration
B = Width of surface deposit
H = Depth of surface deposit
s, s_1, s_2 = Plate thicknesses
t = Thickness of backing plate
I = First run; II = Second run
Suffixes 1 and 2 refer to the first and second runs
u = Transition zone between parent and weld metal
w = Heat-affected zone in parent metal, whose structure has been changed by the heat.

With joints it is primarily important for the metal to be fused right through, i.e. good penetration, in which case the internal form coefficient φ_e dominates. This not only gives some indication of the welding method, but also allows conclusions to be drawn regarding the composition of the seam. The larger φ_e is, the greater the proportion of filler metal in the weld metal, and vice versa. Due to the intensive arc effect of automatic welding, the main fusion takes place at a depth, i.e. in the parent metal. Accordingly, smaller values of φ_e will be obtained. In the efforts to obtain as flat a seam as possible, or in other words a high value for the external form coefficient φ_a, the reinforcement of the seam should not be too large in this case.

For surfacing, however, the conditions are reversed. The aim is to melt as much filler metal as possible, while producing as little penetration as possible. In this case it is most important to obtain a low external form coefficient φ_a, since the aim is to obtain a high but broad surface deposit.

For the various welding processes the form coefficients will differ somewhat; in general they will be within the following limits.

Form coefficient		Kind of weld	
		Joints	Surfacing
Internal	φ_e	0.5–5	2–10
normal		1.2–3.5	4–8
External	φ_a	2–8	1–6
normal		4–6	2–4
A good, reliable seam form is obtained by adhering to the normal values			

Factors Governing the Form of the Seam

The major influence on the form of the weld, both with manual welding and automatic welding, is exerted by the quantity of heat developed by the arc. The larger this is, the greater the capacity of the process; the more heat available for fusion of the parent and filler metals, the higher the efficiency. But during welding, the whole of the available heat is never employed solely for fusion; some of it is lost by radiation and convection. Consequently the efficiency of the heat transfer by the arc decreases with increasing arc length, and rises when the electrode is immersed in the molten pool. The high fusion rate and rate of deposit of modern automatic arc welders depend mainly on the optimum utilization of the available energy and the high current density attainable in the electrode. The efficiency is therefore higher than with manual welding. If, in the latter process, values of 25% are attained, they rise to about 75% for automatic arc welding. The available amount of heat is determined primarily by the welding current, but also, within their limits, by the welding voltage and the current density. With manual welding these values can only be varied by quite a small amount so that little influence can be exerted on the internal seam form of a welded joint, which is of course the most interesting factor. The form depends to a large extent on the preparation of the joint, but the success of the weld is mainly a question of the skill of the welder himself.

Conditions are otherwise for automatic welding. The preparation of the joint (bevelling the edges, gap width) becomes noticeably less important in its influence and will not be dealt with further. But here there are other possible ways of effecting improvements, which at the same time increase the capacity; therefore subsequent remarks will concentrate on the effect of the welding values on the form of the seam.

For extended and reliable seam formation it will be necessary to utilize various auxiliary means, which are already dictated by the basic setting of the automatic welder or the power source. Thus the basic settings and the welding values together are the factors which govern the form of a seam, and they can be graduated according to their effect, as follows:

1. Welding current I_s [A]
2. Welding voltage U_s [V]
3. Welding speed v_s [cm/min]
4. Current density J_s [A/mm²]
5. Electrode diameter d [mm]
6. Kind of current (a.c. or d.c., electrode positive or negative)
7. Distance from contact (i.e. length of electrode tip carrying current)
8. Position of the electrode (pointing forwards or backwards)
9. Position of the workpiece (downhill or uphill welding)
10. Earth connection.

The remarks that follow give an indication of what form of weld is obtained when one or more of these factors are varied.

Welding Current

The current—the most important welding value—exerts the greatest influence on the rate of welding and thus on the form of the weld, whether the latter be a joint or a surface deposit. Increasing the current raises the current density; the rate of deposit and the size of the molten pool likewise grow; penetration becomes deeper, but the width of the weld remains almost unchanged (1 in Fig. 2).

The depth of penetration naturally depends on the welding process, too, as well as on the kind of current and the polarity and diameter of the electrode. The current I_s needed for a desired penetration h_e is given by the formula:

$$I_s = \frac{h_e \cdot 100}{k_e} \quad \text{in A}$$

where k_e is a factor characteristic of the welding process and has the dimensions mm/100 A.

The following average values may be assumed for k_e:

For CO_2 welding (99·97% pure)	1·5–2·5
Flux-cored electrode with CO_2	1·4–2·2
Submerged-arc with d.c., electrode positive	1·0–2·0
Submerged-arc with a.c.	1·1–1·5
Submerged-arc with d.c., electrode negative	1·0–1·2
Welding with mesh-coated electrode	0·8–1·2

The upper values above apply for welded joints with bevelled edges or wide gaps, the lower values to surfacing and square-butt welds without any bevelling.

The mean rate of deposit for submerged-arc welding may be taken as roughly 1·5 kg/h for a current of 100 A. With CO_2 welding, however, this value is a good deal higher (2·0 kg/h) while with mesh-coated electrodes it is lower (1·0 kg/h). The welding current is therefore the main factor governing the depth of penetration in a welded joint, but also for the amount of filler metal deposited, and thus indirectly for the composition of the seam.

The following are some important practical rules:

- When welding joints the extensive fusion of the parent metal is accompanied by the risk of it collapsing; therefore the welding current should be set low enough to prevent at least ⅓ of the material thickness from melting.

- For surfacing, the current, particularly for the first run, must not be too high because the proportion of the parent metal in the molten pool has to be kept small in most cases.

- In the case of peripheral seams the diameter of the workpiece is also an important factor for the seam formation. The current, which primarily determines the size of the molten pool, is limited in terms of the diameter as there would be a risk of the molten metal flowing away if the pool were too large. The pool may therefore not be larger than can be controlled.

A curve $I_s = f(D)$ (4 in Fig. 2) illustrates the relationship between the maximum admissible welding current I_s and the diameter D of the workpiece. This curve shows that trouble is not likely to be encountered with workpieces of large diameter. For small-diameter workpieces though, there are limits to I_s, and the weld has to be executed in several runs.

Peripheral seams in the fabrication of containers are a special case of peripheral welding. Multi-layer welding will be adopted even though it might be feasible to execute the weld in a single run, thereby improving the structure of the actual weld metal.

Welding Voltage

The next most important factor governing the form of the weld is the voltage U_s. Normally this is directly related to the current; every change in voltage causes a change in the current, and vice versa. The welding voltage represents the potential difference between the tip of the electrode and the surface of the molten pool. It varies with the length of the arc, but has only a slight influence on the amount of filler metal deposited as it primarily influences the width of the seam (2 in Fig. 2). To a lesser extent the penetration is also affected. On increasing the length of the arc, i.e. on raising the arc voltage, the depth of penetration diminishes while the width of the seam grows. Thus the relationship between the width of the seam and the depth of penetration can be influenced by varying the voltage.

With submerged-arc welding increasing the welding voltage by 1·5 V causes the width of the seam to grow by about 1 mm. The penetration, on the other hand, decreases by only 0·5 mm. It would be quite logical to assume that increasing the amount of energy ought to cause the penetration to increase. But this is not so, likewise the rate of deposit of the wire becomes less, assuming equal current. The explanation for this is that when welding with a longer arc a much greater proportion of the energy in the arc is lost by radiation and convection than is the case when the arc is shorter. This accounts for the deep penetration of CO_2 welding, which is performed with a short arc and a high specific load.

Despite the reduced penetration accompanying an increase in voltage, the proportion of parent metal which is melted grows, at the rate of roughly 10% for 1 V rise. With submerged-arc welding the flux consumption is also noticeably changed: the lower the voltage, the less flux is required.

Often when the flow of slag is too great this can affect the welding process; the unduly large skin of slag becomes jammed in the joint, particularly with fillet welds

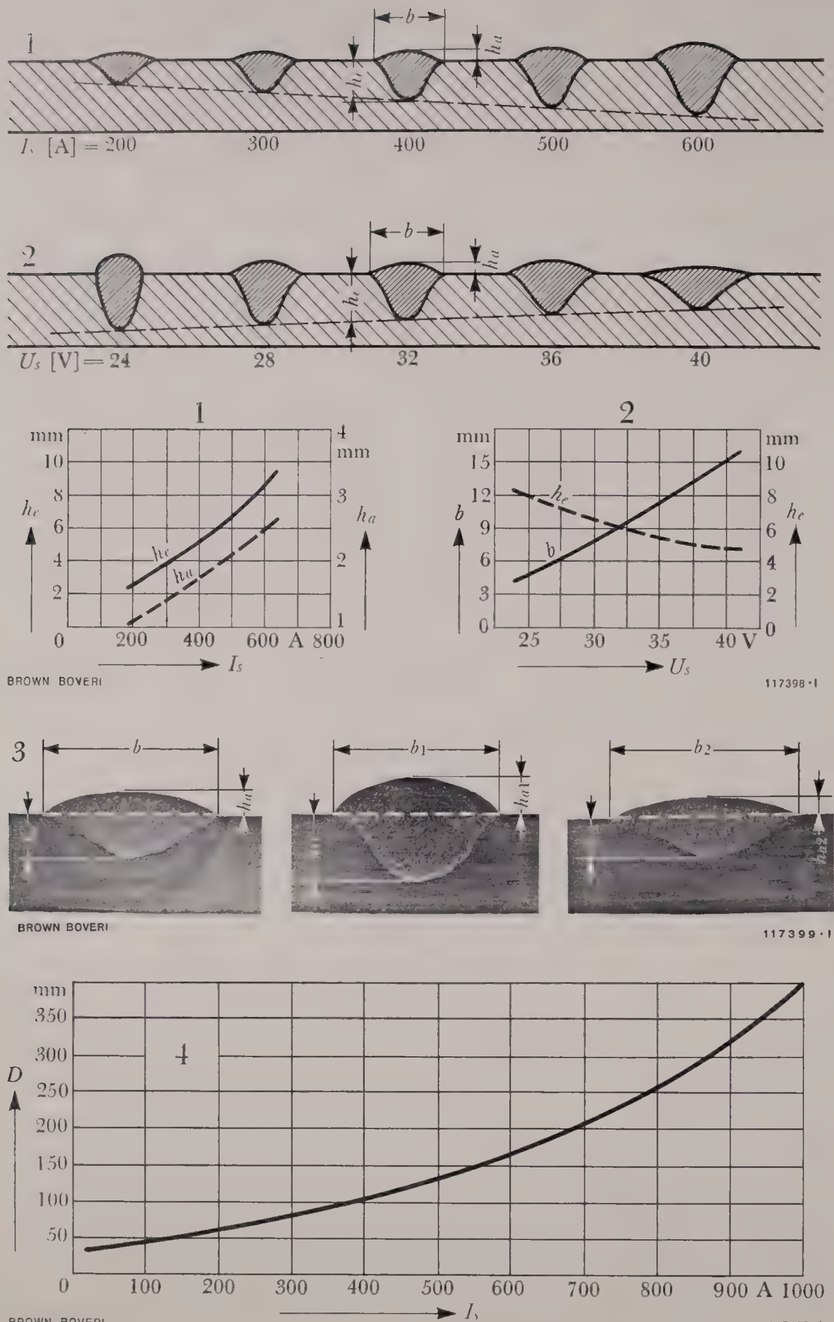


Fig. 2. – Effect of the welding current I_s and voltage U_s on the form of the seam

1: The penetration depth h_e is primarily governed by the current I_s. The width b of the weld and the reinforcement h_a increase only slightly with rising current.

2: On increasing the voltage U_s the seam grows broader, the penetration decreasing by half the increase in width.

3: Macrographs showing the effect of increasing the current and voltage.

Left: (without subscripts) initial state with basic settings

Middle: (subscript 1) with increased current

Right: (subscript 2) with increased voltage

4: The maximum admissible current I_s for peripheral welds is governed by the diameter D of the workpiece. If the current were too high, a poor weld would result (excessively convex or concave) or the molten metal would flow away from the pool.

or multilayer single-V butt welds. A reduction in the welding voltage of 1–2 V can create much more favourable conditions.

The absolute value of the change in the penetration due to varying the welding voltage is very small. At heavy currents and deep penetration there is no need to allow for the effect of the change. When welding thin sheet at light currents, however, the influence is considerably more pronounced, and it is recommended that every change in voltage be accompanied by a current correction.

The magnitude of the arc voltage is determined from experience, being governed primarily by the process being used and the welding current (see Tables I–IV).

Welding Speed

The efforts aimed at increasing the welding capacity of an installation led not only to an increase in the capacity of the arc, by increasing the power source, by twin-wire welding [6], twin-head welding, or by increased current density, but also to an increase in the speed of welding. With modern mechanized processes it is already possible to achieve speeds up to 4 m/min. These speeds can be attained particularly with gas-shielded welding methods. But of course here the capacity of the arc is somewhat reduced, since the maximum permissible welding current is only about 600–800 A. Excessive spatter would be produced if heavier currents were used. With most of the conventional submerged-arc processes a speed of 15–150 cm/min is usual, at currents up to 2000 A, or higher in exceptional cases. Thus the capacity of these processes is superior to that of gas-shielded welding, at least at the present time. Considered all round, the speeds of mechanized welding are far higher than those attainable with manual welding, where only 5–25 cm/min is possible.

But when the welding speed is increased, the uncertainty regarding the quality of the weld is bound to grow. There is a greater tendency for undercutting and pores to be produced; incomplete fusion and cracks can also occur. When welding at more than 150 cm/min, it is no longer permissible to rely on the skill of the operator when a directional correction has to be made to the welding head, either across the seam or in the height of the nozzle. He is no longer in a position to follow the progress of welding properly and can only keep an eye on the welding values set on the controls. In such cases automatic readjustment of the head is essential, either by sensors or controlled by a motor.

If a weld is executed at too high a speed with too heavy a current density, it will inevitably contain incompletely fused zones and excessively high reinforcement (see Fig. 3). The remedy is to place the electrode at a more acute angle relative to the seam and to weld with the electrode pointing forwards. Reduction of the current or the use of a larger diameter of electrode usually renders this measure superfluous, so that welding speeds of 150 cm/min or more are attainable without inclining the electrode.

TABLE I

Submerged-arc welding

Wire diameter d [mm]	Welding current I_s [A]	Welding voltage U_s [V]
1.2	75– 150	24–26
1.6	125– 225	25–29
2.4 (2.5)	200– 375	27–32
3.0 (3.25)	350– 650	30–35
4.0	525– 900	33–40
5.0	750–1200	37–45
6.0	900–1500	40–50

TABLE II

Gas-shielded arc welding

Wire diameter d [mm]	Welding current I_s [A]	Welding voltage U_s [V]
0.6	75–125	18–23
0.8	100–200	20–25
1.0	150–250	23–30
1.2	200–300	25–35
1.6	250–450	27–38
2.0	350–500	28–42
2.4	400–600	30–45
3.25	500–800	32–48

TABLE III

CO_2 welding with flux-cored electrode

Wire diameter d [mm]	Welding current I_s [A]	Welding voltage U_s [V]
3.25	300–600	24–28
4.0	400–750	26–32
5.0	500–900	28–36

TABLE IV

Welding with mesh-coated electrode

Diameter of core wire	Outside diameter	Welding current I_s [A]		Welding voltage U_s [V]	
d [mm]	D [mm]	basic electrode	acid electrode	basic electrode	acid electrode
2.5	6.5	250– 350	175–250	21–25	19–22
3.25	7.25	300– 400	200–300	22–26	20–23
4.0	8.0	350– 500	250–400	23–27	21–24
5.0	9.0	450– 650	350–500	24–28	22–25
6.0	10.0	600– 850	400–600	25–29	23–26
7.0	11.0	800–1000	500–800	26–30	24–27

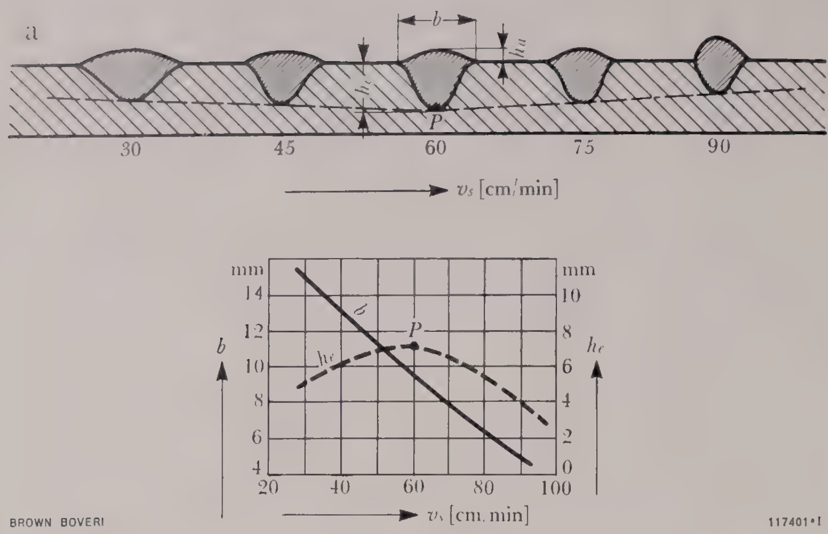
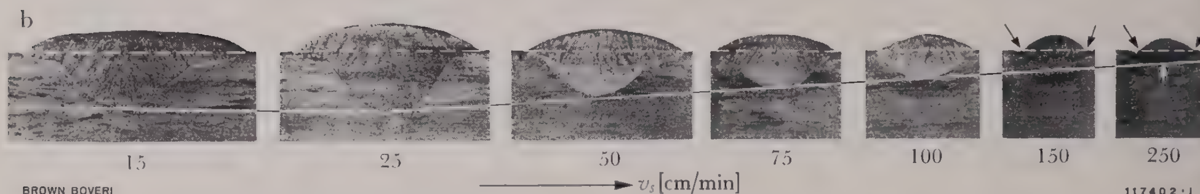


Fig. 3. – Effect of the welding speed v_s on the form of the seam

a: When the speed is reduced, the seam becomes broader, flatter and also smoother. The depth of penetration h_e only increases very slightly and then suddenly diminishes. This critical point is different for all welding currents and can only be determined by trials.



b: A selection of macrographs illustrating a change in welding speed. It can be clearly seen that, as the speed is increased, the total fusion and penetration area diminishes. If the speed is made too high, undercut, pores, inclusion or incomplete fusion are inevitable.

The excessive reinforcement occurring at high welding speeds is due to the rapidity with which the sides of the seam cool. This can be remedied by slightly raising the welding voltage, because at such speeds the inclined arc column cannot reach the sides of the seam properly and must therefore be lengthened.

The speed must always be considered in relation to the welding current and voltage and always has a particular effect on the appearance or form of the finished weld.

The speed, however, also influences the internal form of the weld (Fig. 3a). On reducing the speed a larger molten pool is produced; penetration becomes deeper and broader, but of course only to a certain extent (point P in Fig. 3). If the speed is too low the arc is almost vertical; the molten metal at the foot of the column thus hampers the fusion of the metal beneath it at the root of the weld and the penetration diminishes. Only a slight increase in the speed is necessary to improve the penetration, but only to a certain extent though. If it is speeded up too much the total penetration area decreases, i.e. the depth and width of penetration. The limiting speed, at which the advancing molten pool ceases to hamper penetration, grows with the current. In general though it may be said that, in comparison to the change in current, the penetration depth varies little with a change in the welding speed.

The proportion of the parent metal in the weld metal also increases with the speed, because the amount of electrode deposited per unit length decreases, although the penetration area becomes only slightly smaller. Hence the speed has a similar effect on the composition of the weld to the current. Here too the proportion of parent metal in the weld metal grows, though in this case it is due to the increased penetration effect and the greater heat concentration of the arc. A speed increase of 20% corresponds roughly to about 25% less electrode

or filler metal melted per unit length, but only 15% less parent metal. Of course this reduces the amount of energy, or heat, absorbed per unit length of the seam, with the result that the total penetration area is smaller.

On increasing the speed of welding and using a thinner electrode, that is to say, welding with a higher current density, a greater heat concentration is attained at the weld. In other words, the higher the welding speed, the more rapidly the temperature decreases in front of the arc and, consequently, the less heat there is available to spread out before the arc and preheat the weld. This fact can be utilized very effectively when welding thin sheet, since at higher speed the risk of the sheet buckling is less, because the heat cannot run ahead of the welding point. Another important fact is that, for submerged-arc welding, not every flux permits speeds higher than about 100–150 cm/min.

The properties of the flux therefore demand attention. The susceptibility to porosity also tends to increase with greater welding speed. By increasing the current or reducing the voltage it is possible to effect improvements here too.

It may be added, in conclusion, that it is always advisable to determine the best speed by carrying out a weld on a test-piece first, that is, if no tables are available.

Current Density

The current density J_s, measured in A/mm², has a similar effect on the form of the weld to the current I_s, that is to say increasing the current density increases the rate of deposit and the penetration (Fig. 4). In this case the proportion of parent metal in the weld metal also increases.

The increasing width of the weld with diminishing current density is partly related to the freedom of movement of the arc spot on the surface of the molten pool. The smaller the diameter of the wire, the smaller the freedom of movement of the arc. Consequently, not only the penetration becomes deeper, but the width of the seam is also reduced (in contrast to an increase in the current). Enlarging the diameter of the electrode wire, while keeping the same current, causes the arc spot to dance more on the surface of the molten pool, the penetration becomes broader and less deep. The depth of penetration is roughly proportional to the diameter of the electrode wire.

Owing to the greater penetration effect of higher current densities it is possible to increase the capacity of an existing welding installation, i.e. to increase the attainable penetration by reducing the electrode diameter. For this reason there is an ever-growing tendency

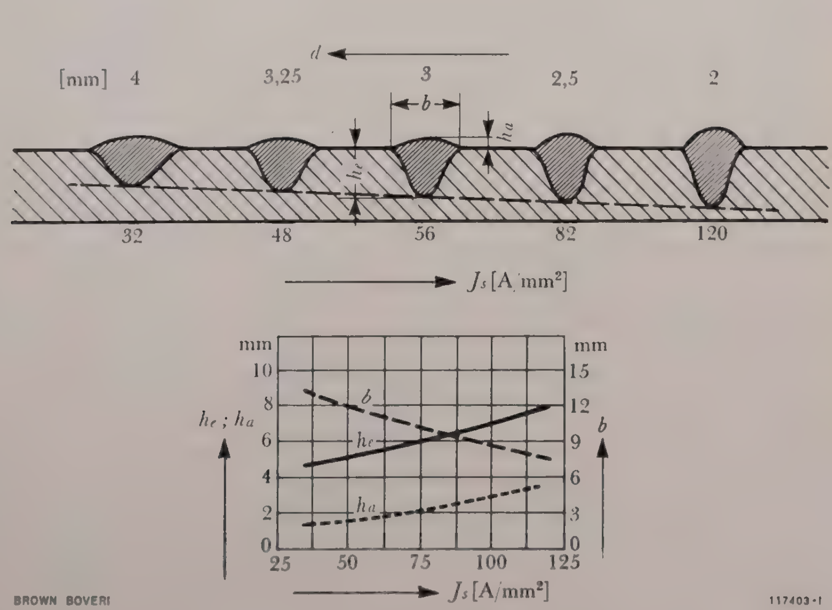


Fig. 4. – Effect of current density J_s on the form of a weld

With increasing current density, or decreasing wire diameter, given the same current and voltage, the penetration h_e increases while the width of the seam b decreases.
Also more filler metal is deposited, with the result that the reinforcement h_a grows slightly.

nowadays to weld with the thinnest possible wire at the highest possible current density. With automatic arc welding the usual densities are from 20 to 350 A/mm². The higher values in this range apply to the thin wires used for gas-shielded welding.

The current density is governed by the specific load capacity of the electrodes. Approximate values are:

Submerged-arc welding	25–125 A/mm² (min.–max.) 40– 80 A/mm² (normal)
Gas-shielded welding	75–350 A/mm² (min.–max.) 125–300 A/mm² (normal)

Mesh-coated electrode (spiral wire) with

basic electrode	20– 70 A/mm² (min.–max.) 25– 60 A/mm² (normal)
acid electrode	15– 50 A/mm² (min.–max.) 20– 40 A/mm² (normal)

It is possible to utilize the permissible current-carrying capacity of the electrodes very effectively: supposing, for instance, the capacity of a power source is not enough to allow a desired penetration to be achieved, a thinner electrode can be used and the necessary penetration thus achieved with a relatively low current.

Diameter of the Wire

The quality of the electrode must match that of the material to be welded. The diameter is obtained from the permissible current-carrying capacity of the wire, and the thickness of the material. The construction of the wire (bare, flux-cored or mesh-coated) and the composition (alloying components) are different for all automatic arc-welding processes. The specific current-carrying capacity increases with decreasing diameter. The permissible load capacity, however, must not be exceeded, otherwise the penetration and the appearance of the seam will be irregular. With larger wire diameters the penetration and the amount of filler metal deposited decrease—assuming constant current, voltage and speed of welding—but the width of the seam grows very slightly (Fig. 4).

For the most important contemporary welding processes it is advisable to employ wire diameters in accordance with Tables I–IV on page 453 for the appropriate current range.

Kind of Current

Automatic arc welding can be performed either with d.c. or a.c. The choice of the most suitable power source is mainly governed by questions of price and of a technical nature. The correct employment of the two kinds of current, or even their combination (as in twin-head welding), guarantees a first-class joint.

Alternating current

The power source in this case is a welding transformer. Its advantages are its low initial cost and the small amount of maintenance it requires, compared with other power sources. The small amount of arc blow may be regarded as a technical advantage. In many cases, though, it is not possible to use a.c. for automatic arc welding, for example with certain parent and filler metals. A disturbing factor in operation is the poorer stability of the arc compared with d.c., as well as the greater difficulty in striking. In the latter case, however, provided local regulations permit, conditions may be improved by the employment of a high-frequency unit. With submerged-arc welding a greater susceptibility to porosity may be detected, which accounts for the attainable welding speed being less than with d.c.

Direct current

Here a converter or a rectifier may be the power source. These are of course more expensive to purchase than transformers, but from the technical aspect they can offer more advantages because d.c. is more universally applicable. The welding speed which can be attained is higher than for a.c., and there is also the advantage that, by changing the polarity, it is possible to influence the form of the weld and its composition. A drawback which must be accepted is the greater arc blow.

Polarity

Not only the kind of current, but also the polarity of the electrode on d.c. exerts an appreciable influence on the dimensions of the seam. Given the same current, welding speed and arc voltage, the depth of penetration is different in the two cases.

The deepest penetration is obtained on d.c. with the electrode positive, the least with electrode negative. The reason for this is that the cathode (i.e. the workpiece) receives more heat than the anode (the electrode) when the latter is positive.

In contrast to manual welding, for automatic welding with negative electrode the melting coefficient of the electrode is larger than with positive polarity; this means, more filler metal is deposited and the reinforcement is greater. Here the greatest amount of energy is consumed in melting the filler wire. Consequently the width of the seam is also broader with negative electrode than with positive.

When welding with a.c. the polarity changes a hundred times per second. As a result, the outward appearance of a seam welded with a.c. also differs from one welded with d.c., with the electrode positive or negative. The dimensions are somewhere between the two, and there is the same relationship between the dimensions and the welding data. The rate of deposit with a.c. is also roughly between that obtained with the two forms of d.c. welding (Fig. 5).

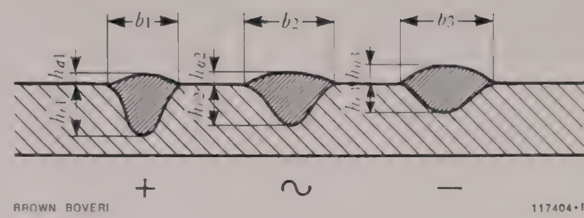


Fig. 5. – Effect of the kind of current and polarity of the electrode on the form of a seam

+ The deepest penetration is obtained on d.c. with positive electrode.

— The highest rate of deposit, with a corresponding increase in the reinforcement, is obtained on d.c. with negative electrode.

~ A good seam form is obtained on a.c. The dimensions of a weld executed on a.c. are roughly half-way between the two d.c. polarities.

The subscripts 1, 2, 3 refer to the different kinds of current and polarities.

Free Length of the Electrode

When welding with heavy current densities it is advisable to apply the voltage to the electrode wire shortly before the tip. Consequently the current is transferred to it shortly before, or even in the centering nozzle. The hole-nozzle, as it is called, is therefore becoming increasingly popular because it performs the tasks of centering the wire and transferring the current to it at the same time. This protects the wire from premature preheating. A slight curvature in the wire ensures that the contact pressure is adequate. The free length of wire protruding from the nozzle, according to Joule's Law, exerts an increasing influence on the amount of filler metal melted per unit time: increasing the free length increases the rate of deposit, so that the wire feed rate has to be stepped up. As a result, the reinforcement of the seam is higher. But the free length of wire must not be too long because, apart from the severe wear suffered by the contacts, owing to the excessively high temperature, the welding process itself becomes less steady; the penetration and width of the seam fluctuate, and its surface becomes rough and pitted. The free wire lengths recommended for the various types of automatic arc welder, amounting on the average to 20–40 mm, should therefore be adhered to.

Angle of the Electrode

The width of the seam and the depth of penetration can also be influenced by the angle of inclination of the electrode, i.e. whether welding with the electrode pointing forwards or backwards. From the geometrical form of a longitudinal section through a seam with inclined electrode, it is obvious that the penetration into the plate is bound to decrease, because the arc strikes the metal at an angle.

When welding with the electrode pointing forwards, it is possible to attain higher speeds than when the wire is vertical because the arc extends better to the edges and melts them properly. The seam is somewhat flatter and broader, and undercut is avoided. At extremely high welding speeds and the necessary higher welding currents (normally used for welding thin sheet-metal), it is common practice to tilt the workpiece forward, at the same time inclining the electrode forwards up to an angle of $\beta = 30°$ (Fig. 6a). However, if the inclination is too great, there is a risk of the molten pool flowing

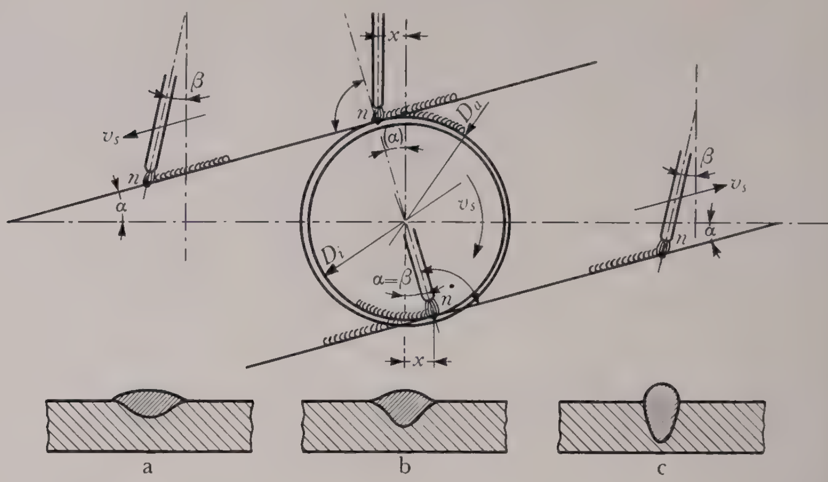


Fig. 6. – Inclination of the wire and workpiece (β, α) for longitudinal or peripheral welds

To improve the form of the weld either the wire or the workpiece, or both, may be tilted.

a: Pointing the electrode forwards in the direction of the seam and simultaneously tilting the workpiece forwards (downhill welding).

b (upper): Downhill welding with vertical electrode

b (lower): Uphill welding

c: Formation of the weld with the electrode pointing backwards, with the workpiece tilted back at the same time (uphill welding)

v_s = Welding speed (arrows)
n = End crater of the seam
x = Displacement of the electrode
D_i = Inside diameter of workpiece
D_a = Outside diameter of workpiece

Generally with all these positions conclusions can be drawn regarding peripheral seams inside and outside.

beneath the electrode and obstructing the fusion process, thus reducing penetration. In this case the seam will be considerably broader.

If the wire is inclined backwards, on the other hand, the seam becomes narrow and deeper, but with rather more reinforcement.

Angle of the Workpiece

Tilting the workpiece (uphill, downhill, peripheral welds) is a measure often resorted to when welding sheet-metal. Here it is necessary to distinguish between downhill welding (as in Fig. 6a) and uphill welding (as in Fig. 6c). For peripheral seams, especially with small diameters, the workpiece is automatically tilted (relative to the electrode) owing to the need for controlling the molten pool.

Downhill welding (a and b in Fig. 6, for instance) is when the end crater n is lower than the finished seam. It is therefore immaterial whether the electrode is moved in the direction of welding (Fig. 6a) or whether the workpiece is moved opposite to the welding direction (Fig. 6c).

Uphill welding is when the end crater n is higher than the seam (Fig. 6b, below, and c).

With peripheral welds a downhill weld is obtained by displacing the electrode by the distance x against the direction of rotation of the workpiece, welding taking place before the top dead-centre position (see Fig. 7a). Consequently specialists commonly refer to this as the "eleven o'clock position". Downhill welding is also employed with high welding speeds, so that the molten pool can be protected by the downward pressure of the slag. This measure can often be utilized with advantage when welding with mesh-coated electrodes, owing to the relatively small amount of slag produced by the coating.

With downhill or peripheral welding on the outside, where the electrode is displaced against the direction of rotation (Fig. 6b), the liquid metal attempts to flow downhill, or underneath the arc. The penetration will decrease in this case. Therefore, with peripheral welding, the position of the electrode must be corrected until it is normal to the sheet, i.e. pointing to the centre of rotation (Fig. 7a). By increasing the displacement x with peripheral welds, the risk of burning through is

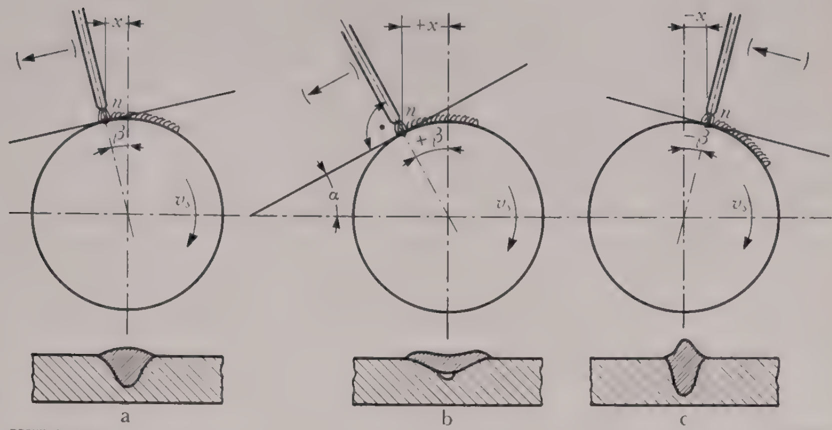


Fig. 7. – Peripheral welding with the electrode displaced by a distance x and correction to the inclination of the wire (β)

a: To control the molten pool and its shape, the electrode has to be displaced by a distance x against the direction of rotation of the workpiece. The electrode should be pointed at the centre of rotation.

b: If the displacement $+x$ is too great, the penetration decreases and the seam becomes broad and wavy.

c: When displaced in the opposite sense $-x$, i.e. shifting the electrode in the direction of rotation, the penetration increases, but the seam becomes narrow, with unduly high reinforcement.

n = End crater of the seam

diminished and the form of the seam is improved. In this case the seam is inclined and, owing to the effect of gravity, the thickness of the molten layer in the crater increases. The arc spreads beyond the edges of the joint on to the workpiece and becomes more mobile; the width of the penetration also increases, the reinforcement thereby becoming flatter. If the displacement x were too large, i.e. the inclination of the electrode (Fig. 7b), the result would be that the molten metal would flow so far back under the arc that the middle would cave in and the edges be excessively built up. The workpiece inclination which is still possible amounts to $\alpha = 6$ to $8°$ for downhill welding; when welding thin sheet-metal, however, the angle may be increased up $15°$ owing to the small size of the molten pool. From the permissible inclination it is possible to calculate the displacement x for peripheral welds. In the latter case, though, the displacement x is largely governed by the welding current and the speed of welding.

For uphill welding and peripheral welding with the electrode displaced in the direction of rotation (Fig. 7c), the molten pool tends to concentrate under its own weight. With increasing angles of inclination α and β, and greater displacement $-x$ a large molten pool forms with deep, narrow penetration, as a result of which the reinforcement of the seam grows appreciably.

When welding internal peripheral seams the conditions are rather similar to those for uphill welding (Fig. 6c). This weld can also be corrected by pointing the electrode forwards (electrode inclination β with simultaneous displacement x) opposite to the direction of rotation of the workpiece.

Fig. 8. – Effect of making the earth connection at the side on the internal shaping of the weld

These macrographs prove that attention must also be paid to the earth connection to the workpiece. When this connection is made at one side, the arc is blown to that side and the penetration is accordingly skew. The result is then lack of coincidence between the upper and lower run.

TABLE V

Effect of various factors on seams produced by automatic welding

No.	Factor		Change	Penetration depth h_e	Seam width b	Reinforcement h_a
1	Welding current		+	+++	+	++
2	Welding voltage		+	—	++	——
3	Welding speed		+	—	———	++
4	Current density		+	++	—	++
5	Electrode diameter		+	——	+	——
6	Current, with different kinds of current and electrode polarities	d.c., electrode positive	+	+++	+	+
		d.c., electrode negative	+	+	+++	+++
		a.c.	+	++	++	++
7	Free wire length		+	—	+	+
8	Electrode inclined forwards		+ (++)[1]	— (——)[1]	+ (++)[1]	— (—)[1]
	Electrode inclined backwards		+ (++)[1]	+ (—)[1]	— (++)[1]	+ (+)[1]
9	Downhill welding (workpiece tilted forwards)		+ (++)[1]	— (——)[1]	+ (++)[1]	— (+)[1]
	Uphill welding (workpiece tilted backwards)		+ (++)[1]	+ (—)[1]	— (+)[1]	+ (++)[1]
	Peripheral welds, outside, with displacement		+ (++)[1] (—)[2]	— (——)[1] (+)[2]	+ (++)[1] (—)[2]	— (+)[1] (++)[2]
	Peripheral welds, inside, with displacement		+ (++)[1] (—)[2]	+ (—)[1] (+)[2]	— (+)[1] (—)[2]	+ (+)[1] (++)[2]
10	Earth connection					

Meaning of the symbols:

+	slightly larger	—	slightly smaller
++	definitely larger	——	definitely smaller
+++	much larger	———	much smaller
( )[1]	change too large	( )[2]	change too small

Earth Connection

The earth connection of the workpiece can also affect the form of the seam. This may be attributed to the arc blow or the current transfer at the point of connection. Arc blow obeys approximately the same laws as with manual welding. It has been demonstrated that it can be quite appreciable, even when welding with

a.c. The arc always tends to be blown away from the point of connection. In consequence different depths of penetration are obtained, and penetration becomes skew, even when the connection is at the side. There is consequently a risk of insufficient coincidence in the root of a joint welded from both sides (Fig. 8). Furthermore an increased susceptibility to porosity may be observed, due to the fact that the joint is not properly melted by the arc when it is blown to one side or forwards along the seam. The low gas pressure is insufficient to force the gas through the viscous weld metal to the surface, with the result that pores and a rough surface are produced. It is therefore convenient to make the earth connection at the beginning of the weld, in other words to weld away from the connection. This connection must be made to the bright metal in order to minimize contact resistance. The welding and earthing cables must of adequate gauge, otherwise the voltage drop will be too high. Good insulation of the cables is important because earth currents can also lead to disturbances. The connection must be tightened up sufficiently, best of all using screw clamps. When welding peripheral seams there is a risk of damaging the earth cable; as a result, pivoted earth clamps have proved very successful in practice.

Conclusions

Only when a reliable check is kept on the welding values, duly allowing for all aspects of the factors affecting the form of a weld, and always employing the best welding process and most suitable automatic arc welder, can a welded joint or surface deposit of the desired form and quality be obtained.

The welding values are obtainable from tables giving approximate values based on practical experience. However, if no such tables are available, the various values can be roughly calculated as follows:

1. Welding current: According to a rule of thumb $I_s = h_e/k_e$ (see the chapter on welding current). If the calculated figure is higher than the load capacity of the available power source, or if it ought to be reduced, having regard to the quality of the weld, it will be necessary to weld in several runs, which for thick plates is an advantage from the quality aspect in any case. If, having carried out a test weld, a macrograph is prepared, and the practical value does not agree with the calculated figure, the current can be corrected accordingly.

2. Welding voltage: Should be selected in accordance with the values suggested in Tables I–IV, for the appropriate current.

3. Welding speed: This is also best obtained from existing tables, or else determined by preliminary test welds.

4. Current density, wire diameter: The choice of the wire diameter is governed by the current calculated and the permissible specific load capacity of the wire. Tables I–IV also contain approximate values applicable here.

Once the welding values have been determined by trials, they should be noted on a record card, as with machine tools, which then becomes a good reference for similar work at a later date. During the actual welding process the settings must be checked, allowing for the effect of all factors on the form of the finished weld (see Table V).

(KME) P. NOBBE

Bibliography

[1] A. SCHMID: The new Brown Boveri arc welder. Brown Boveri Rev. 1956, Vol. 43, No. 7, p. 272–7.

[2] P. NOBBE: Die maschinelle Lichtbogenschweissung mit den Brown Boveri Schweissautomaten Typ U 1200. Technische Rundschau 1956, No. 9.

[3] A. SCHMID: Shielded-arc welding with argon and tungsten electrode. Brown Boveri Rev. 1959, Vol. 46, No. 3. p. 210–21.

[4] A. SMARCAN: Automatic resurfacing of steel-mill rolls by welding. Brown Boveri Rev. 1957, Vol. 44, No. 6/7, p. 276–85.

[5] E. O. PATON: Automatische Lichtbogenschweissung, chap. VIII, p. 172–83. Carl Marhold Verlag, Halle (Saale), 1958.

[6] A. SMARCAN: The twin-wire automatic arc welder and its applications. Brown Boveri Rev. 1957, Vol. 44, No. 6/7, p. 271–6.

PRACTICAL APPLICATIONS OF TIG WELDING WITH STEEL, NON-FERROUS METALS AND NICKEL ALLOYS

621.791.85

For welding joints which have to comply with very strict requirements the method known as tungsten inert gas or TIG welding has given excellent results, not only with light metals but also with other materials. The present article describes how certain special materials are dealt with and draws attention to certain properties which have to be taken into account during welding. It is taken for granted that readers are acquainted with the process and its applications to light metals, as the subject is comprehensively covered by the literature.[1] This article concludes with some remarks on the possible automation of the process, and comments on test methods.

Gas-Shielded Welding of Carbon Steel and Low-Alloy Steel

GAS-SHIELDED welding of low-alloy and carbon steels can nearly always be performed satisfactorily, though it is not always economical because ordinary arc welding with coated electrodes is technically quite sufficient. When welding deep-drawing sheet, where particular stress is laid on the appearance of the seam and on a minimum of finishing work being required, the question takes on quite a different aspect. Above all, this is true when mechanical guidance of the electrode holder or the workpiece is feasible. Then, owing to the higher welding speed, the process becomes more economical.

Therefore gas-shielded welding of low-alloy and carbon steel becomes interesting for batch production, especially when the process can be performed automatically, because the operator is able to attend to other preparatory work in the meantime. Another remarkable feature is that TIG welding produces seams free from scale, both on the inside and on the outside. There is usually no need for any finishing. The fusion and heat-affected zones are narrow, so that distortion of the workpiece remains small (Fig. 1). Particularly suitable are objects made from deep drawing steel with appropriately prepared joints, such as folded seams, which can be welded without any filler metal. However, the parts must be pressed together and there must be no air-gap between the folded parts, otherwise pores will be the result.

A deciding factor is often the state of the parent material. It is usual to distinguish between unkilled steel and killed steel. The latter is fully deoxidized before casting—by addition of deoxidizers such as silicon or aluminium—to bind the free oxygen. This is not done with unkilled steel, with the result that this always contains gases which bubble up in the molten pool during welding, giving rise to porosity. Killed steel is therefore preferable for gas-shielded welding.

Unkilled steel, such as Thomas steel, cannot therefore be welded with complete freedom from pores. But the pores are formed predominantly at the surface, so that the weld may nevertheless be gas-tight (Fig. 2). By choosing the optimum welding speed and current, and when the joint is well prepared, it is often possible to weld unkilled steel without porosity. In most cases, though, the welding speed has to be reduced, thereby tending to make the process uneconomical. If unkilled steel is welded with a filler wire, the wire should have a high Si content, or be alloyed (e.g. Cr-Ni 18/8 + Mo) to facilitate deoxidization of the molten pool.

[1] A. SCHMID: Shielded-arc welding with argon and tungsten electrode. Brown Boveri Rev. 1959, Vol. 46, No. 3, p. 210–21.

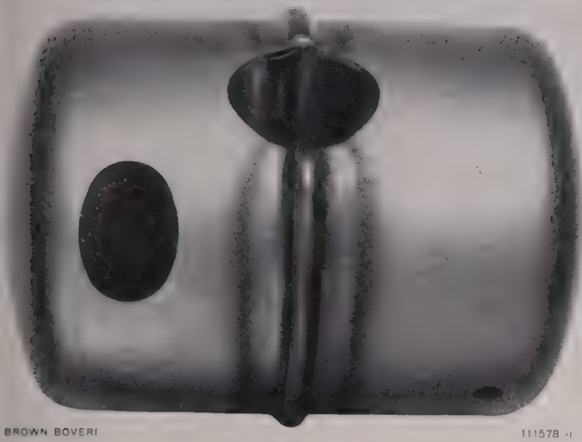


Fig. 1. – TIG-welded container of deep drawing steel

The welded joint is free from scale both inside and outside. Although the steel is unkilled, the seam is free from pores, owing to the optimum welding speed chosen and the complete lack of clearance between the two parts to be joined. This achievement cannot normally be guaranteed with this kind of steel.

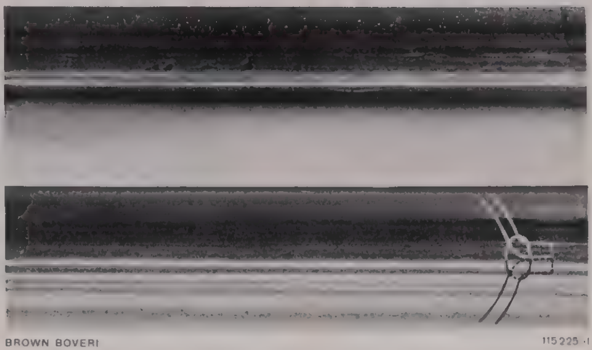


Fig. 2. – Folded joints between sheets of killed and unkilled steel

On the unkilled steel (top) pores do not occur along the whole seam but are localized. Despite the visible pores, the seam is gas-tight. The lower seam, in killed steel, is absolutely free from pores and has a smooth surface, free from oxide inclusions. On the inside a fine, slightly reinforced seam is produced, without any argon filling, thus indicating the good penetration.

Killed steel, steels with a high carbon content or alloyed steels, which are specially deoxidized, exhibit less inclination towards porosity. They can be welded with or without a filler wire. When welding multiple-run seams, it may be necessary to remove an oxide film before carrying on with welding, thus avoiding pores.

Stainless and Heat-Resistant Steels

Gas-shielded welding has given excellent results with stainless and heat-resistant steels and has therefore been widely adopted by industry. The main advantages are the good quality of the welds, due to the fact that none of the alloying elements are burnt out and the molten pool is effectively shielded against the effects of oxygen and nitrogen. Owing to the high welding speed the heat-affected zone is small and there is consequently little distortion of the workpiece.

No particular difficulties are experienced when welding high-alloy steels with gas shielding. The melting point of the material is lower than that of carbon steel, the thermal conductivity, and hence the dissipation of heat from the welding zone much smaller than copper or aluminium, so that the amount of heat required is also less. Pre-heating is only necessary in exceptional cases. Since, with gas-shielded welding, there is no risk of chromium oxidizing and producing slag in the arc, there is no likelihood of inclusions in the finished seam. It is possible to produce seams whose properties closely resemble those of the parent metal, and which require little or no finishing. Of course, the composition of the parent material and the filler metal must be carefully observed. If necessary, the instructions of the steel-makers should be obtained before welding is commenced, or the conditions determined by experiment.

The forms of welds used for alloy steels are similar to those used with mild steel, although the shape of the root may differ from one object to another. Thin sheets requiring a square-butt joint may be welded with or without filler wire. For thick objects, where single or double-V seams are used, usually only the root run is welded with gas shielding. Thus on the inside of the root there appears a small, well fused bead, provided adequate precautions were taken to prevent the access of air. For this purpose it is customary to use cover plates or, for hollow objects, to fill them with an inert gas, such as argon, nitrogen or a mixture of N_2 and H_2. For complicated objects shielding gas can also be conveyed to the root of the seam—by a manually or mechanically operated nozzle. Without shielding an ugly, scaly seam is produced, which is seldom uniformly

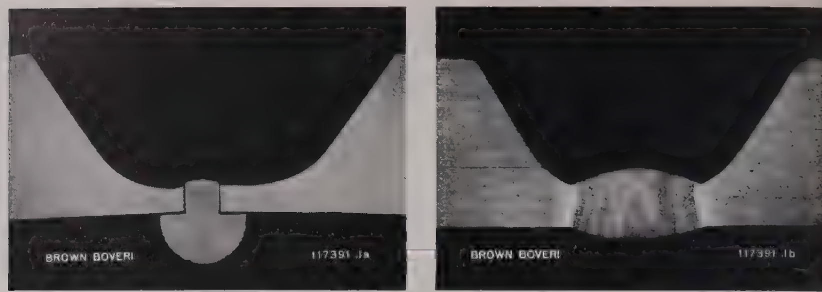


Fig. 3. – Macrographs of a sealing weld between tubes of Cr-Ni 18/8 welded by the EB Weld process

The inserted ring helps to centre the joint, and acts as filler material. The weld is executed from the V side. Both inside and outside a clean, slightly reinforced weld is produced. (Three times natural size.)

fused. For the subsequent build-up of single-V seams the usual method is to weld by hand with coated electrodes. If the seam is built up by TIG welding, the beads should be narrow and placed with as high a current and as high a speed as possible. This keeps the heat-affected zone small and prevents the formation of coarse grains. For technical and economical reasons stainless steels often have to be welded to parts of carbon steel, low-alloy steel, copper, etc., which is quite feasible, and permissible too.

In order to reliably weld the roots of joints between pipes of high-alloy steel, special processes have been devised. Properly executed TIG welds from the outside produce seams free from scale and defects, and a root bead of good appearance with only a slight reinforcement on the inside. A very good method is known by the name EBWeld (see Fig. 3). A T-shaped wire is used to centre the workpieces and, at the same time acts as filler. During welding, a localized stream of gas is applied, or the pipes are completely filled with shielding gas (Fig. 4). On large objects which are suitable for machining, the ring insert is replaced by a stepped joint, which also permits good fusion (Fig. 5). To act

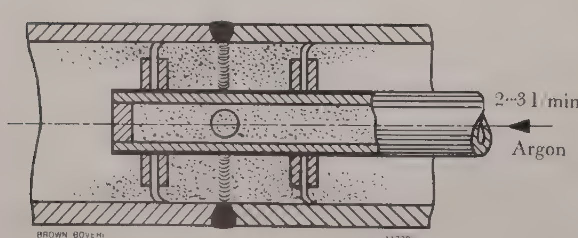


Fig. 4. – Local shielding by inert gas at the root of a butt weld between pipe sections

The actual shielding space, which is sealed off by sleeves of asbestos or leather against the walls of the tube, is fed with gas through a pipe.

Fig. 5. – Gas-shielded root weld, showing the original stepped shape of the joint

This joint was welded vertically, without any filler material, the object being filled with argon, resulting in a well fused seam. The reason for the slight reinforcement is the shrinkage. This shape of seam is mainly used for rotating objects with large diameters.

(Five times natural size.)

as a backing for the inner bead in batch production, rings of ceramic material, quartz or plastics can be used; these are struck off when welding is finished.

Since it is not always possible to weld in the down-hand position when joining pipes during installation, very skilled welders have to be employed, who are capable of welding all kinds of joints uniformly and reliably, regardless of the position. Constant arc length is essential, otherwise the current and voltage will fluctuate, resulting in irregular fusion. It is difficult and sometimes even impossible to check the penetration from one side. When the root is automatically welded the necessary settings have to be checked by a prior trial, but for manual welding it is only possible to rely on the experience and skill of the welder.

Gas-shielded welding may also be employed with advantage for steels clad with chrome steel or chrome-nickel steel. TIG welding is particularly suitable when it is impracticable to weld the cladding layer from the clad side. The edges of the joint have to be prepared after the fashion shown in Fig. 6, i.e. the basic material has to be suitably cut away so that the cladding can be welded with or without filler material. Care has to be taken not to melt any of the base metal because, to ensure that the cladding retains its corrosion resistance in the finished object, the weld must be just as resistant to corrosion as the original cladding. If the back of the weld is adequately protected against access of air, the root bead will be perfectly fused and free from scale. The rest of the joint between the parts of mild steel can usually be filled up by arc welding with coated electrodes.

The execution of joints at the ends of tubes or similar objects demands special adaptation at the flange in order that the joint may be heated and fused uniformly (Fig. 7, 8, 9). TIG welding is preferably performed automatically, although it can be carried out by hand by a skilled welder. For large diameters automatic TIG welding is recommended. This also applies to very thin seams. The parts to be joined must be prepared with great care, in particular there must be no air-gap whatsoever between the edges being joined. The stricter the requirements regarding the quality and uniformity of the weld, the greater the accuracy of the rotary manipulator must be (Fig. 10). Since ultrasonic and X-ray tests cannot be used with this kind of seam, the test for sound welding consists of superficial inspection and submission to high pressure, the first to check for cracks, the second for leakage.

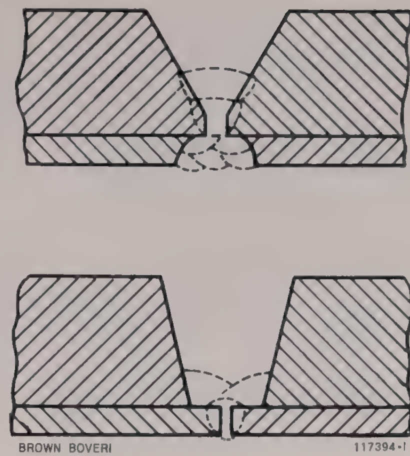


Fig. 6. – Joints between parts of clad steel

a: Prepared for welding with coated electrode, welding from both sides.

b: Prepared for gas-shielded welding. The basic metal must be cut away in such a manner that no mixing of metals take place when the seal run in the cladding is welded.

For seams in thin sheet which are subjected to severe mechanical stresses and also have to be vacuum-tight, a method of solder-welding is used. The filler solder in this case does not consist of the usual non-ferrous metals, but of the elements used to alloy the steel, i.e. Ni, Cr

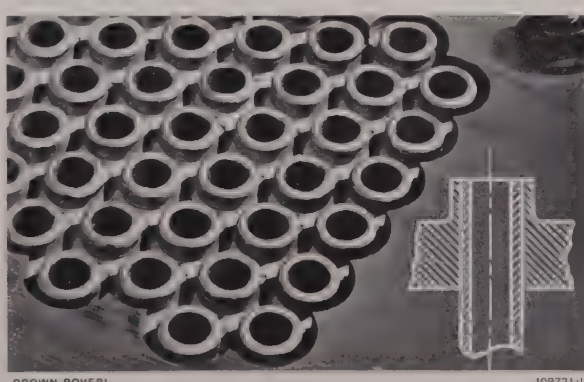


Fig. 7. – Part of a tube-plate of Cr-Ni 18/8 in a heat exchanger, welded under gas shielding

The flange is mechanically prepared as shown in the sketch, thus facilitating uniform heating and fusion.

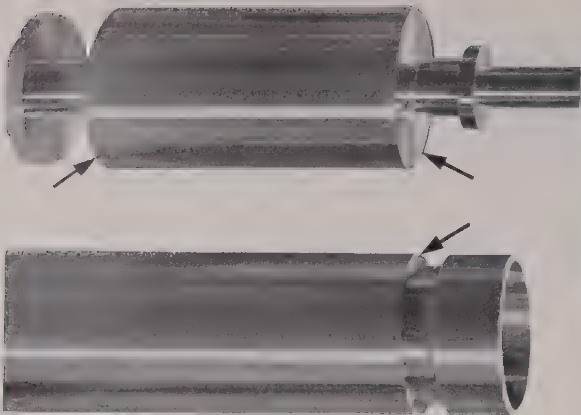


Fig. 8. – Sealed rotor and spacer tube of an acid pump

The jacket is welded to the flanges by TIG welding. The material used depends on the medium in which the pump runs, though in most cases Cr-Ni 18/8 is used. For iron chloride, liquid chlorine and acids, titanium has been used, while for sulphuric and hydrochloric acid good results have been obtained with Hastelloy. (Courtesy Rütschi Pumps, Brugg, Switzerland)

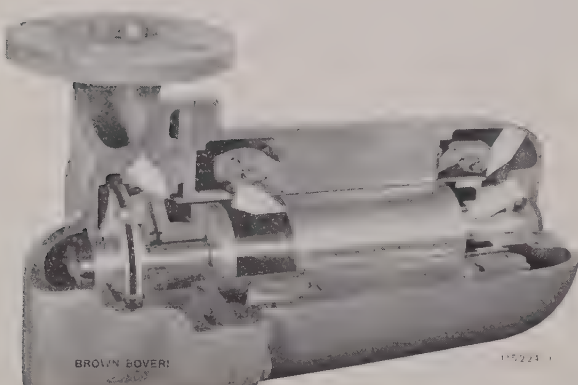


Fig. 9. – Cutaway view of an acid pump

The arrows indicate where the various welds are located. (Courtesy Rütschi Pumps, Brugg, Switzerland)

Fig. 10. – Chamber of a high-vacuum pump

with which vacuum pressures down to 10^{-10} mm Hg are produced, thus demanding completely gas-tight welds. All welds are executed by hand or on a rotating manipulator. The material is stainless steel.

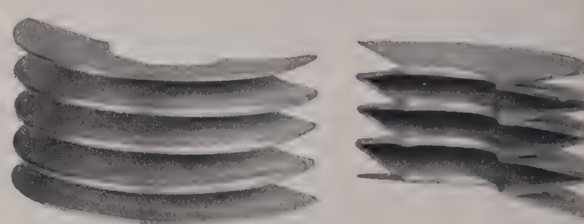


Fig. 11. – Section through a spring bellows of high-alloy steel

for which the inside and outside seams were welded under inert gas on a simple rotating manipulator. These welds have to be completely gas-tight and are subjected to mechanical and thermal stresses in service.

and Mn, having melting points between 1000 and 1200 °C, or higher. Such joints are executed almost exclusively by TIG welding. In the machined part, as shown in Fig. 12, a slot is cut to correspond to the insert, and the strip of solder is laid in it. Welding produces an edge seam, part of the inserted solder flowing between the joined parts. This improves the strength and gas-tightness of the joint and reduces the risk of cracking from the back of the seam (Fig. 13).

Surfacing

TIG welding is also an excellent method for surfacing; with it very good quality deposits are obtained. Admittedly the mixture with the parent metal is slightly more extensive than with conventional arc welding, but the method is more economical and achieves better quality than other methods of welding. Provided the surface is perfectly clean and bright and the correct welding

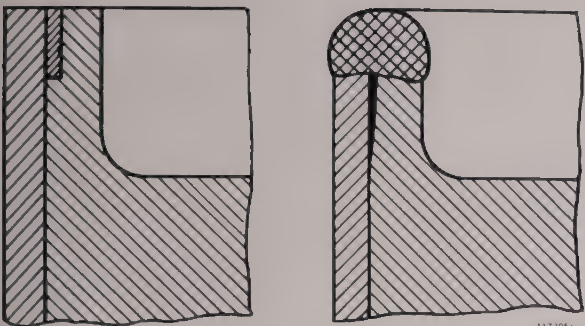


Fig. 12. – Preparation of a joint for vacuum-tight weld

A strip of solder with a high melting point is laid in a machined groove; when the edge is welded, this solder melts and forms an additional soldered seal beneath the edge weld, thus enhancing the mechanical strength and assuring complete absence of leakage.

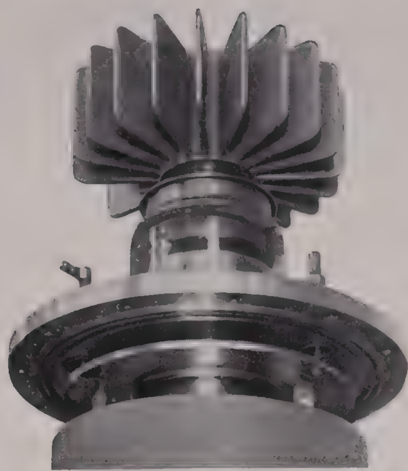


Fig. 13. – Valve assembly on the main anode of a mercury-arc rectifier

The metal joints were welded under inert gas.

technique is employed, slag and oxide inclusions are rare. Since the filler metal is added visibly and under control to the molten pool, incomplete fusion is avoidable.

The deposited material depends on the particular requirements with regard to wear or corrosion. In the construction of tools, cutting steels alloyed with C, Cr, W, Mo, V and Co, having hardness values of over 60 Rockwell units are common. Owing to the very slight penetration there is very little mixing with the parent metal, and the deposited surface layer is very hard. It is sometimes necessary to carry out surfacing on clad steel coated with ferritic or austenitic stainless steel, copper or its alloys. For this task gas-shielded welding is ideal

Fig. 14. – Valve seating built up by a deposit of stellite, the sketch (inset) showing a section through the weld

Quantity of stellite deposited 3·2 kg. During the welding operation the parent metal is pre-heated to 500 °C, thus reducing the risk of cracking when it cools.

and, when performed properly, produces the best results. In order to attain the desired surface quality at least two layers have to be deposited, otherwise the mixture with the parent metal would have an adverse effect. Fig. 14 illustrates a stellite deposit on a valve seating. This austenitic alloy with inclusions of carbides of Cr, W and Mo, gives the best results when TIG welded.

Depending on the nature of the parent metal and the filler wire, the latter may have to be heated, otherwise cracks may occur on cooling, even though this may take place slowly. An excellent method of checking the deposited layer is the dye penetration method. A liquid dye is painted on the cleaned surface of the joint, which works its way into finest hair cracks and subsequently shows up on a layer of chalk paste.

Copper and Its Alloys

To weld copper and its alloys under a shielding gas it is necessary to know something of the metallurgical and physical actions. At a temperature of about 500 °C copper possesses very little mechanical strength. Therefore attention must be paid to shrinkage strains, which can easily lead to cracks. But difficulties may also arise from the tendency of the heated copper to absorb oxygen. Owing to the formation of copper oxide, pores are formed and the tensile strength diminishes. The high solubility of hydrogen in heated copper must also be taken into account.

In contrast to all other metals, when welding copper a thin liquid pool of molten metal is produced, having very little surface tension and consequently liable to flow. Furthermore, when welding without a backing, the workpiece becomes red-hot in the welding zone, with the result that, very quickly, too much of the parent metal is melted and the process cannot be kept under control. The welding equipment must therefore provide facilities for continuous control of the heat and current, and the welders need special training for this material. Since copper possesses a high conductivity, large workpieces demand a very high input of heat by pre-heating. In most cases the welding process must begin with increased current, which can be reduced later when the molten pool has been created. The welder must have an eye for good fusion and penetration, and yet avoid overheating. Copper which has been overheated can be recognized by the typical brick-red fracture. It is possible to counteract overheating by adding material in good time and at a faster rate. At the end of the seam there is a considerable accumulation of heat, necessitating further reduction of the current.

In every respect TIG welding fulfils the prerequisite conditions for welding copper, having particular regard to the parent metal, the filler metal, the preparation of the workpiece, the manipulator and the method of welding. The quality of the finished weld depends on choosing the correct quality of copper and filler rods. Only quite small amounts of impurities can adversely affect the weldability and the quality of the weld. For stressed elements which have to be welded, only specially deoxidized copper ought to be used. If copper containing oxygen is used, it may lead to an enrichment of cuprous oxide in the grain boundaries, causing embrittlement of the workpiece, and cracking, favoured by the greater shrinkage of the copper.

To assist in the deoxidization and improvement of the quality of copper welds, slightly alloyed filler wires are employed. Suitable deoxidizing agents are phosphorus, silicon, and manganese. It is mainly the phosphorus which reduces the copper oxide in the liquid state, forming a copper phosphate slag which forms a scum on the molten pool. The amount of phosphorus in the filler rods is less than 0·05%, otherwise the seams would tend to suffer from hot crack. Additives containing less than 1% of silver, nickel, titanium and vanadium increase the strength and produce poreless, fine-grain welds. As a result of adding silver, the molten pool becomes rather more viscous and can be controlled better by the welder. Therefore, when welding out of the downhand position it is advisable to use filler wire containing silver.

In practice ordinary rolled copper is often used, and this is one of the main reasons for difficulties experienced with gas-shielded welding. Copper sheet less than 1 mm thick is best welded under tension on a backing. The seams are most uniform when the joints are folded (90

or 180°) for about 2 mm. When under tension the edges of the folds should make contact as nearly uniformly as possible. Sheets 2 mm thick are bent up by about 45° (Fig. 15, 16).

Thicker sheets are welded without any backing, otherwise too much heat would be lost. With sheets 3–4 mm thick attractive seams of good quality can be welded in the downhand position with filler metal, the rear being covered if possible, or protected with shielding gas. To avoid adverse effects by the atmosphere on the relatively large glowing zone, the use of welding pastes is recommended for such cross-sections. Coating the edges of the joint with paste prevents scale being formed by the advancing heat. Fluxes should not be used for thin sheets because their residue is difficult to remove before the seam is hammered. It is an advantage to hammer shielded welds when severe stresses are produced, owing to the rigidity of the construction, and these have to be eliminated to avoid cracking. It is not necessary to pre-heat, except perhaps at the start of the welding operation, in order to be able to maintain the set current during the entire welding process.

Seams in sheet more than 4 mm thick which cannot be hammered after welding, owing to their poor accessibility, are welded in the vertical position. This partly prevents the thin pool of molten copper from flowing away. Hammering the still warm seam greatly helps to improve the structure, brittle copper resulting from cold working being tempered by heating and quenching in water. For thick material a flame as second source of heat on the inside often proves useful. Multiple-layer welds are preferably avoided when welding copper because, owing to the complicated method of applying the heat, flux inclusions and pores can be produced in the seam. Thick plates up to 10 mm thick can also be joined with TIG welding, carried out from both sides simultaneously.

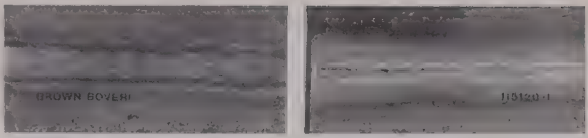


Fig. 15. – Views above and below part of a weld

in a sheet consisting of 96% copper, with 3% Si and 1% Mn (Simbo). This copper alloy has similar properties to pure copper, but it is much easier to weld because a more viscous molten pool is produced. Welded with inert gas on a backing strip, without filler metal. On both sides of the seam the surface is remarkably smooth and regular. Mainly used for the manufacture of domestic heaters.

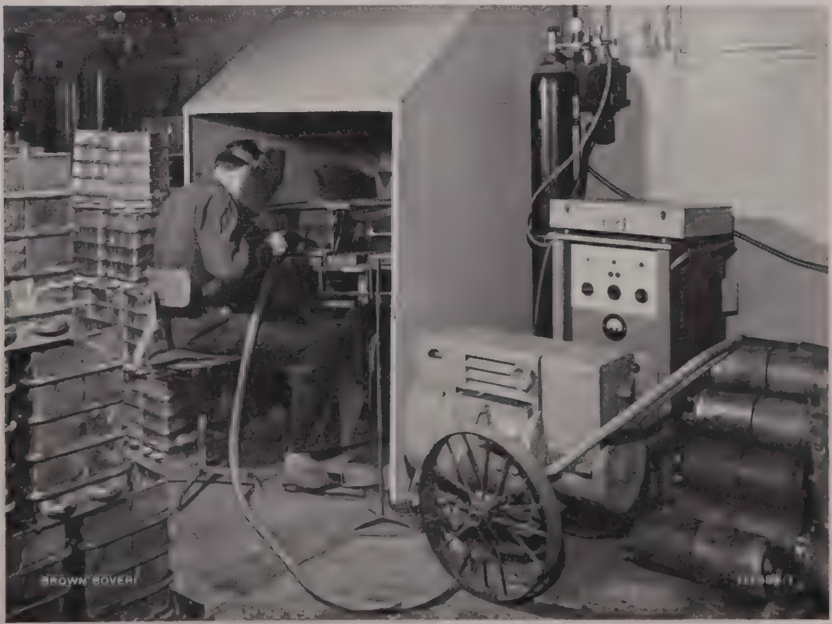


Fig. 16. – Copper cisterns for domestic heaters being welded under inert gas

The control unit is switched on and the current controlled by means of the pedal switch; this procedure is often convenient when seams have to be welded inside restricted spaces.

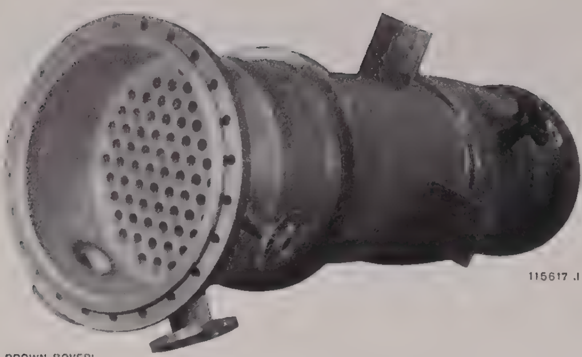


Fig. 17. – Nickel heat exchanger

The tube-plate and connections are TIG welded, all other joints being welded with coated electrodes. Also noteworthy is the nickel-to-steel joint: the supporting feet of boiler-plate were welded direct on to the nickel jacket, which is quite admissible. (Courtesy Carl Canzler, Düren, Germany)

Nickel

Nickel and its alloys are particularly resistant to corrosion and heat, and are ideal for welding under a shielding gas. Primarily pure nickel (99·5% with special additive) is employed. The well-known non-corroding alloy Monel (with 67% nickel, 30% Cu, 1·4% Fe, 1% Mn and traces of other materials) is mainly used for pumps, pipes, engines, pharmaceutical equipment, etc. Another popular alloy containing 60% Ni with 15% Cu and Fe is commonly used for wear-resistant parts subjected to high temperatures and required to exhibit high strength. Also included in the group of nickel alloys are such products as Hastelloy, Inconel and Nimonic. TIG welded seams correspond roughly to the mechanical quality values of the parent metal in the soft annealed state.

To achieve optimum quality, a conscientious effort should be made to fulfil certain prerequisite conditions. The edges of the joint should be perfectly clean, welding being performed with a short arc and at as high a speed as possible. When welding the root, the rear must be sealed with a copper bar, ring backing or by argon, to prevent the access of any air. Nickel and its alloys can also be welded satisfactorily to mild steel, alloyed steel, Cr-Ni and grey cast iron, which may be of economic interest in many cases.

Nickel and its alloys are among the most frequently used materials in the construction of chemical equipment; they can be fabricated successfully into quite complicated installations. Much progress has been achieved in the field of welded fabrication, especially in the last few years, a major share in which is attributable to TIG welding. With careful treatment there is little risk of damaging nickel or its alloys. When preparing the edges of joints, however, it is important to completely remove all traces of sulphur, originating from lubricants or other materials. The filler wires for shielded-arc welding and the coated electrodes for ordinary arc welding must be alloyed to suite the parent metal. Porosity can result if unsuitable filler metals are used, owing to oxidization of the molten metal. In large containers of nickel or its alloys it is quite permissible to specify joints with steels. Hence, for instance, carrying brackets can be welded to the sides of the jacket. However, if the nickel jacket is not very thick, it is advisable to weld the steel parts to a nickel back-plate first, and to join this to the container by a nickel-to-nickel weld afterwards (Fig. 17).

In the chemical industry and process technology various Hastelloy materials are frequently employed. These are non-corroding, high-tensile-strength nickel alloys, which can be welded by the TIG process in the same manner as stainless steel. The weld can be executed with or without filler wire, in which case equivalent or more highly alloyed Hastelloy rods are used, in order to enhance the resistance to corrosion. When welding Hastelloy it is advisable to aim at heating as narrow a zone as possible and to heat the metal up to its melting point as rapidly as possible. This prevents certain alloying elements from precipitating. Hastelloy alloys can be welded to stainless steel, using one of the two metals being joined as filler.

Special Materials

In nuclear reactors and jet engines special materials are often used because, at the high temperatures to which they are subjected, excellent mechanical strength

and resistance to chemical attack are required. As these parts are usually vital to the operation of the machine in which they are included, the welding processes employed must guarantee high quality and constant execution. According to the present state of the art, gas-shielded welding is one of the best processes for this task. It is, however, essential for the work to be carried out by a highly skilled welder, assisted by suitable ancillary equipment.

Among the main special materials are titanium, zirconium and molybdenum, as well as the nickel alloys Inconel and Hastelloy (Fig. 18). Great progress has been made in welding these metals in the last few years, particularly as regards the quality attainable. The above metals and alloys lose their good mechanical properties and their resistance to corrosion when they contain the least amount of oxygen or nitrogen. There is a pronounced risk of gas absorption at temperatures above about 400 °C, so that appropriate precautions have to be taken when welding.

Very small constructional components can be welded completely in argon, by working in a welding chamber (Fig. 19) filled with gas. For large workpieces and site work the electrode holder must be equipped with an additional cowl which completely prevents the entry of air and ensures a steady flow of gas, free from eddies. The cowl must be designed in such a manner that the weld metal is able to cool down for a sufficiently long time under the gas. On certain objects with a suitably shaped seam, it is often quite adequate if a large gas nozzle is employed, through which the gas emerges at a slow rate. Hollow objects can be filled with gas to protect the inside of the root. Before welding starts, the interior must first be scavenged of air by passing gas through to a multiple of the volume of the object. During welding, gas should continue to flow, so that a slight excess pressure obtains on the inside. This produces a reliable, uniform root bead. Shielding the inside of the root is somewhat more difficult on large objects; corresponding backing strips have to be made to completely cover the joint and facilitate a uniform flow of gas. For trial welds it must be remembered that equivalent results can only be obtained when the conditions can also be applied to the actual workpieces.

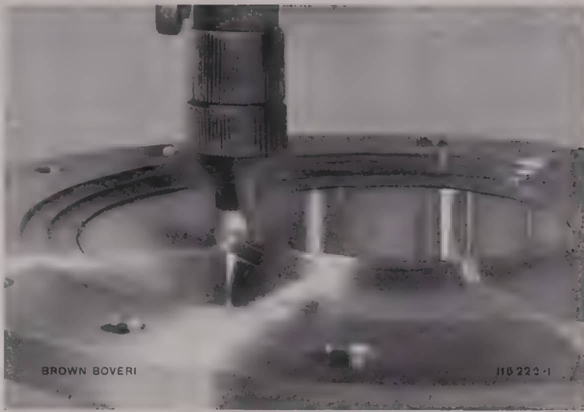


Fig. 18. – Joining a tube to a titanium flange

After welding, the seam is completely polished, provided adequate gas shielding is assured during the process; this can often be obtained with a large nozzle from which the argon emerges slowly.

(Courtesy Rütschi Pumps, Brugg, Switzerland)

Automatic TIG Welding

Gas-shielded arc welding with a non-consumable tungsten electrode was originarily reserved for joints on difficult and relatively expensive workpieces, for economic reasons. By automation of the process the major

Fig. 19. – A simple gas chamber made of plastic foil, used for welding

Welding takes place in an atmosphere of inert gas, a procedure which is often desirable for certain metals, but not always easy to achieve.

(Courtesy Swiss Welding Association, Basle)

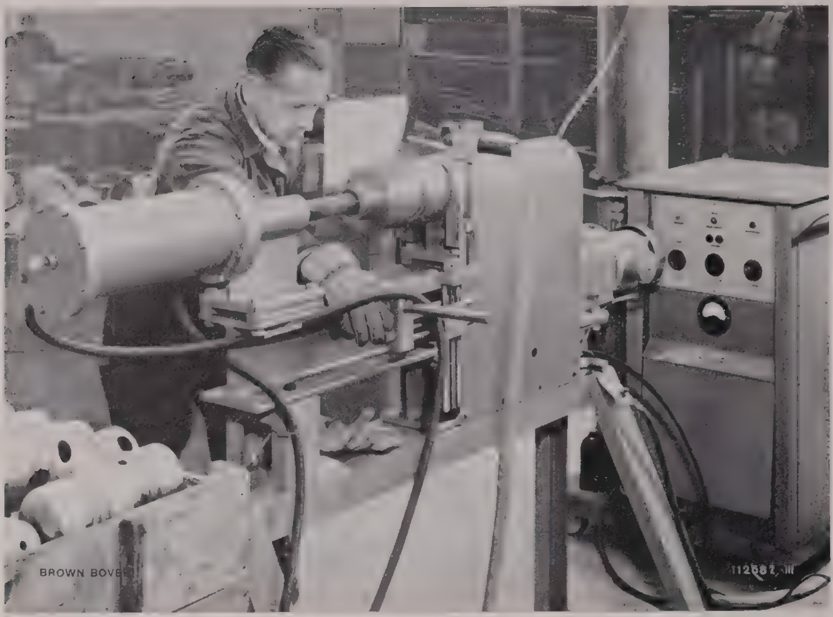


Fig. 20. – Rotary manipulator for welding cylindrical containers under inert gas

Following a single switching operation the entire welding process is carried out automatically. (Courtesy SIBIR Refrigerators, Zurich)

part of the manual work is eliminated and TIG welding is worth employing with batch-produced articles of ordinary steel. Automation has already made considerable progress in a wide range of fabrication processes in the metalworking industry. The equipment required for holding and manipulating the workpieces being joined, or the electrode holder, are designed so that the entire welding operation—for example, rotation of the workpiece, striking the arc, welding, current reduction and return to the starting position—is performed automatically (Fig. 20). Hence modern gas-shielded welding equipment contains the necessary control and switching elements for such a programme. The manufacturers of welding accessories nowadays supply equipment with which quite irregular workpieces can be moved below the torch at constant speed and maintaining constant arc length. For complicated workpieces, e.g. chassis frames of vehicles, where the welds are discontinuous, a number of torches can be operated simultaneously and controlled individually.

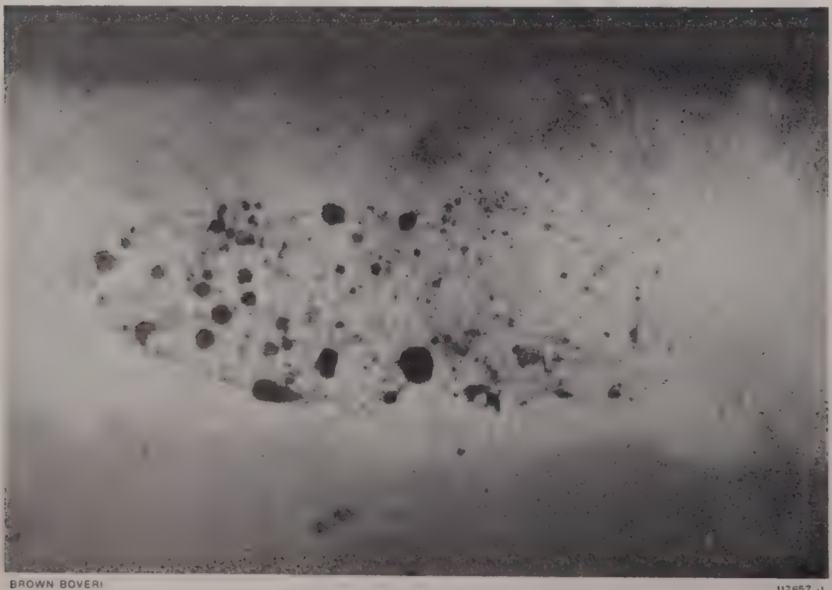


Fig. 21. – Radiograph of a flaw

The pores may be attributed to improper tacking. (Courtesy AIAG, Neuhausen, Switzerland)

Fig. 22. – Radiograph of a flaw

The electrode touched the molten pool, resulting in a deposit of tungsten particles. (Courtesy AIAG, Neuhausen, Switzerland)

Testing Gas-Shielded Welds

Seams welded under inert gas are not only expected to possess a good appearance, but also above-average mechanical properties, which have to be determined by shear, bending and notch tests. High-grade joints also have to be examined for pores, oxide inclusions and other harmful defects, such as cracks. This is mainly done by means of ultrasonic tests and radiography. Particularly when striking the arc and tacking the joint (Fig. 21) the risk of flaws is greatest. When striking and during welding, the workpiece must on no account come into contact with the tungsten electrode, otherwise small particles of tungsten may adhere to the solid workpiece or be melted into the molten pool; this is inadmissible, especially in the construction of nuclear reactors (Fig. 22). The welding circuit therefore has to have an effective high frequency superposed, for striking the arc. If this facility is not available, the arc should be struck on a piece of scrap metal and then taken over to the workpiece.

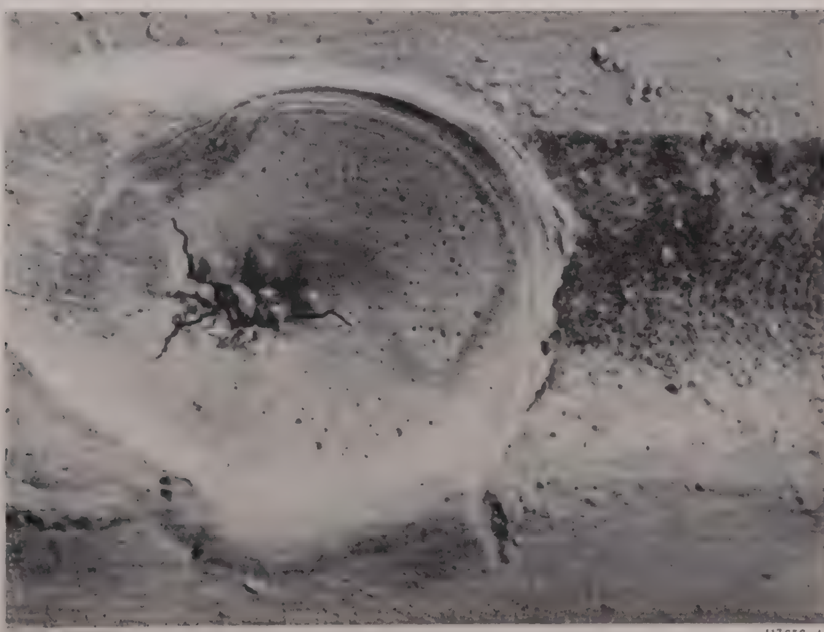


Fig. 23. – Cracks in the end-crater of a welded seam

This defect can be avoided by suitably reducing the current at the end of the run, and reinforcing the end of the seam.

Conditions to be Fulfilled by TIG Welding Equipment

When welding high-grade seams by the TIG process strict requirements are imposed on the welder and the welding equipment. Only highly skilled men will be capable of executing welds of the standard expected. The welder, however, has to be assisted by first-class technical equipment. It should be possible for all instructions to be given from the point of work, either by push-buttons on the electrode holder or by a pedal switch. Since the workpiece must on no account be touched when striking, the arc should be produced with an electrode clearance of 1–2 mm. This is best done with the aid of a h.f. unit. The welder should also be able to control the current, and thereby the input of heat without interrupting the welding operation. This applies particularly at the end of a seam (Fig. 23) where there is a risk of crater formation and cracking. Interruption of welding should not be by drawing out the length of the arc, but simply by switching off the current, allowing the argon to continue flowing for a few seconds to protect the still hot pool and tungsten electrode. The Brown Boveri argon arc welding unit type WS 300 fulfils this requirement in an ideal manner, both when employed for manual and automatic TIG welding.

(KME) A. SCHMID

NON-DESTRUCTIVE TESTING OF WELDED JOINTS, ESPECIALLY IN SECTIONAL ROTORS

621.791.053:620.179.1

The article explains the conditions under which flaws in material can be located by non-destructive testing and describes the capabilities and limitations of the main methods used for testing welded joints. Special reference is made to the tests performed on the welds in sectional turbine rotors.

DESTRUCTIVE tests carried out on random specimens are merely able to provide information regarding the mechanical and metallurgical properties of a weld. The best they can do is to cover systematic flaws. There still remains the uncertainty resulting from chance flaws during welding. Non-destructive methods of testing offer the possibility of considerably reducing this uncertainty; thereby accounting for the welcome accorded to their rapid development. Unfortunately—as is often the case—the expectations seem to have been rather too optimistic sometimes and, because insufficient attention was paid to the principle of a particular method, to have led to disappointment regarding the capabilities of that method.

The remarks which follow will endeavour to indicate the specific capabilities and limitations of the various test methods and to explain them in detail, considering the tests carried out on welded sectional turbine rotors as an example.

General Test Conditions

Non-destructive methods of testing are based throughout on physical principles. A material flaw is a macroscopic irregularity in a definite physical property of the sound material. For it to be indicated at all, it must fulfil certain fundamental conditions:

- The test method must be designed to respond to the kind of inhomogeneity which the flaw represents. For example, a superficial crack filled with foreign matter does not represent any inhomogeneity for the dye-penetration method, as the surface is not apparently interrupted.
- For the particular test method the flaw must represent a certain minimum disturbance. This is governed on the one hand by the test technique, such as the resolving power of an optical system, the sensitivity and frequency of an ultrasonic probe, intensity of X-rays, grain of a film, etc. On the other hand it is also dependent on the structure of the test object, for instance the grain size, surface roughness, and so on. The structure of the test object yields a background disturbance from which the actual flaw must stand out clearly. Of these factors the most frequent disturbance is caused by the roughness of the surface. The stipulation of a certain surface quality (finish) is therefore an important factor as it improves the reliability of the result.

  The internal structure of the material may be so coarse that testing is out of the question.
- The design of the part to be tested must be suitable for the kind of test visualized, and all points where flaws are likely or particularly undesired must be accessible to the test equipment. But since most non-destructive tests are dependent on direction, it is essential for the equipment to be able to obtain the directions in which dangerous flaws can be detected with certainty.

The reliability of the method depends on the extent to which the above conditions are fulfilled. But even

when they are completely fulfilled and the flaw is indicated, there still remains the problem of interpreting the indication, and this can give rise to considerable difficulties, especially for the methods for locating internal flaws. On the other hand, it must not be overlooked that, even with the most exact interpretation of the flaw, the question of whether the flaw is permissible is still a matter of personal judgement.

Capabilities and Limitations of the Various Test Methods

1. Methods for Locating Surface Flaws

Simple visual inspection with the aid of a magnifying glass allows surface flaws to be detected in most cases. Unfortunately, modern aids often suffer from the inherent hazard that this natural method is ignored and blind faith placed in the indication of electronic equipment, although in many cases the latter may be clearly inferior to the human eye. Fig. 1 shows a crack along

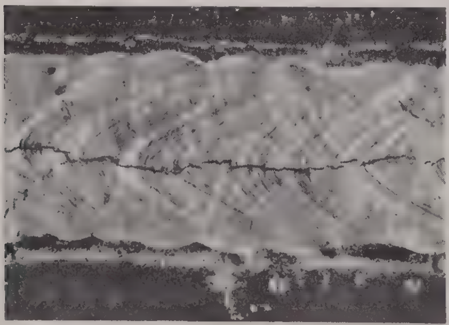


Fig. 1. – Longitudinal cracks in the top layer of a weld

the top run of a weld, which is perfectly visible on the surface of the unmachined joint.

By illuminating the surface at an angle it becomes possible to detect still finer cracks whose width is below the resolving power of the eye, if a directional surface structure exists, to which the crack runs perpendicular. Thus, for example, a very fine fatigue crack was detected with the naked eye, because it ran across the machining grooves of the particular machine part. The same crack was not indicated by the dye-penetration method, although the dye was given 12 hours to penetrate. However, the magnetic-particle test brought it to light immediately.

The *magnetic-particle test* is always preferable when the material itself is magnetic. It is more sensitive than the dye-penetration method and is not governed by the restriction that the flaw must be an open crack in connection with the surface. Cracks which are 3–4 mm below the surface can also be detected magnetically. The magnetization of the test object, however, must be carried out in such a way that the lines of force at the surface run across the suspected line of the flaw, if possible. This is generally not too difficult. However, with complicated shapes, such as at changes in cross-section with sharp edges, the lines of force emerging locally from the surface can seriously affect the magnetic indication. Unfortunately there is so far no simple method by which the true field strength H_t can be measured at any point in the test object, alone and free from all disturbance fields. In many cases though test pieces with artificial gaps can provide adequate information regarding the sensitivity of the indication at the point in question. But here too the possibility of disturbance fields in the region of the test piece must be taken into account. In particular, the fact that magnetic attraction can be felt, for instance by a screwdriver, is by no means an indication that a possible crack at this point would also be indicated.

When inspecting welds the possibility of a false indication at the edge of the seam must always be allowed for. With certain qualities of steel, depending on the state of the structure, there may be a very narrow boundary zone having a much smaller permeability, which gives a pronounced magnetic indication. An example of this is shown in Fig. 2a. But, as can be seen from Fig. 2b, there is in fact no crack. This kind of indication from the edges of seams disappears after suitable heat treatment.

Ultrasonic testing in principle allows tests to be carried out with surface waves (Fig. 3a). This, however, is dependent on a very good surface finish. It is preferable

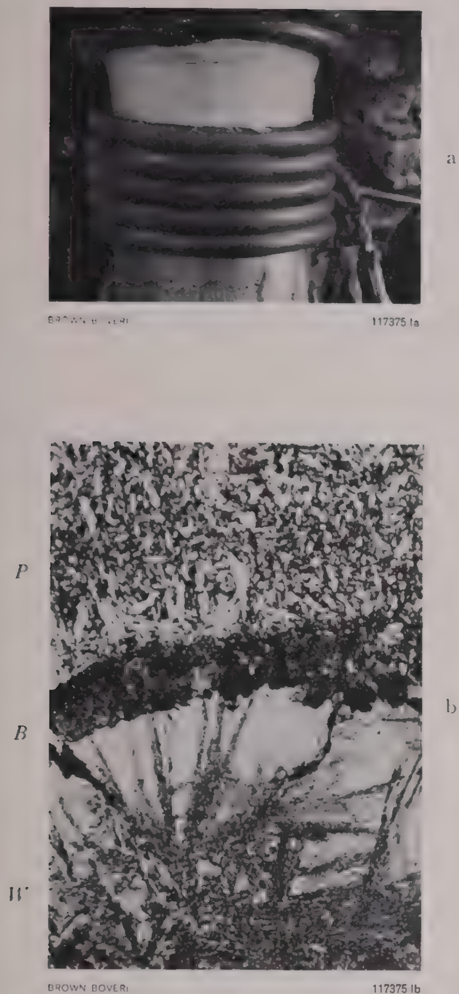


Fig. 2. – Faulty indication from the edge of a weld

a: Magnetic-particle test
b: Macrograph through boundary zone

P = Parent metal
B = Boundary zone
W = Weld metal

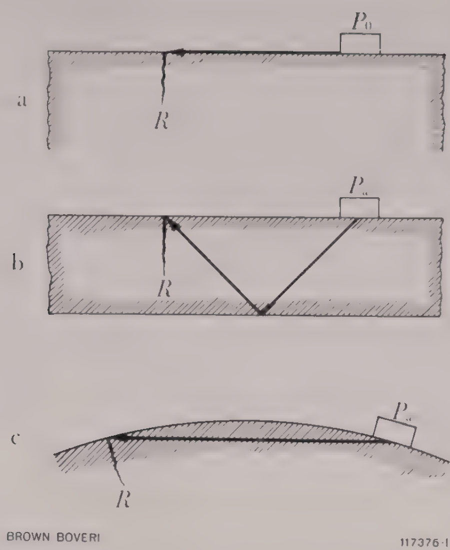


Fig. 3. – Ultrasonic testing for surface flaws

a: Testing with surface waves
b: Testing with reflection from the back wall
c: Testing on a curved surface

R = Crack
P_o = Probe for surface waves
P_w = Angle probe

for the sound wave to strike the edge between the flaw and the surface from the inside (Fig. 3b and c), but of course the favourable conditions for reflection at the edges naturally also apply at all other irregularities in the surface, such as undercut.

2. Methods of Determining Internal Flaws

With *radiography* it is possible to obtain a shadow image of the flaw, provided its minimum extent in the direction of radiation is 0·5 to 4% of the thickness of the irradiated material, depending on the intensity of the X or gamma rays, the thickness of the material and the sensitivity of the film (Fig. 4). This only applies when the extent across the direction of the radiation (width of the gap) is not too small, otherwise the image will not be sharp enough. This implies that very fine cracks are difficult or, indeed, impossible to detect by radiography, and that, even with less fine, flat flaws, their orientation to the direction of radiation can exert a considerable influence on the indication. The ability to recognize a flaw (known as the sensitivity), as a function of the width, depth and the angle of incidence, can be approximately estimated with the aid of the test piece illustrated in Fig. 5a. In Fig. 5b the sensitivity using this method is compared with the theoretical value (i. e. not allowing for lack of definition). The latter was assumed to be obtained when the extent of the gap $a = b/\sin\alpha$ in the direction of radiation is not more than 1% of the irradiated thickness of 40 mm. This condition is fulfilled when

$$D \geqslant a \geqslant T/100$$

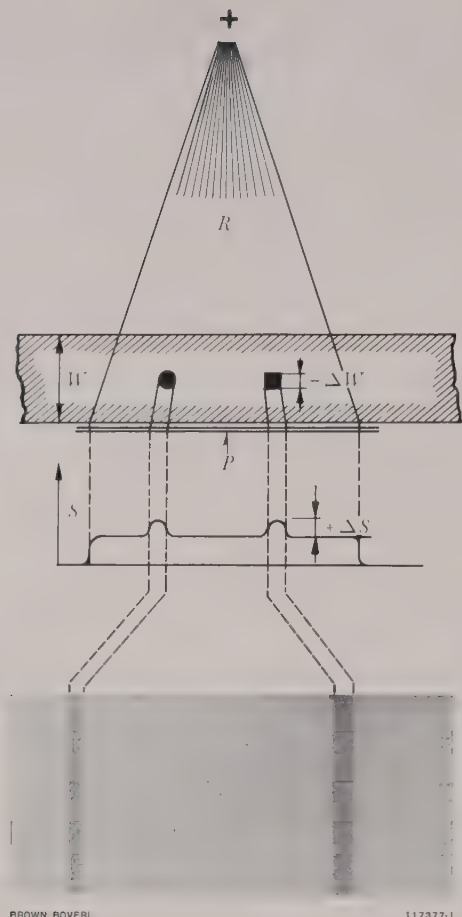


Fig. 4. – Image of a flaw obtained by radiography

W = Wall thickness

S = Intensity of blackening along the irradiated surface

R = Beam of X-rays

P = Photographic plate

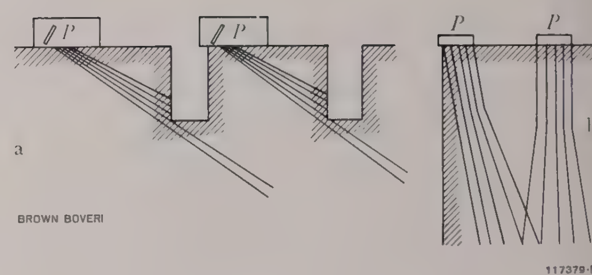


Fig. 6. – Sound shadows

a: Due to projecting corners

b: Due to edge effect

P = Probe (source of sound waves)

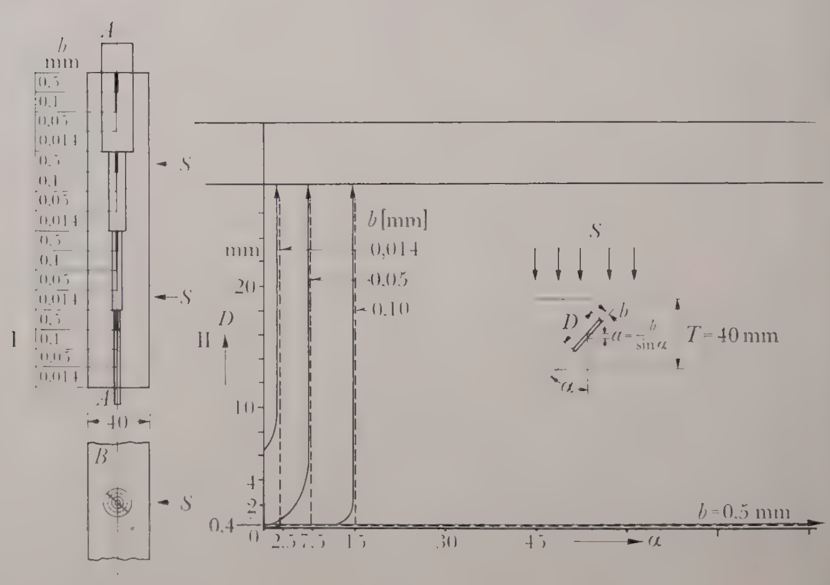


Fig. 5. – Recognition of gaps by radiography: Sensitivity as a function of the depth and width of the gap and the angle of incidence

I: Test piece with gaps of different width, which can be rotated about the axis A–A

B = View in axial direction

II: Calculated (– – –) and measured (——) limits of sensitivity of gaps

S = Direction of radiation

b = Width of gap

D = Depth of gap

a = Extent of gap in direction of radiation

α = Angle of incidence

T = Wall thickness

For calculation of the limit of recognition $a = T/100$ was substituted, regardless of the lack of definition.

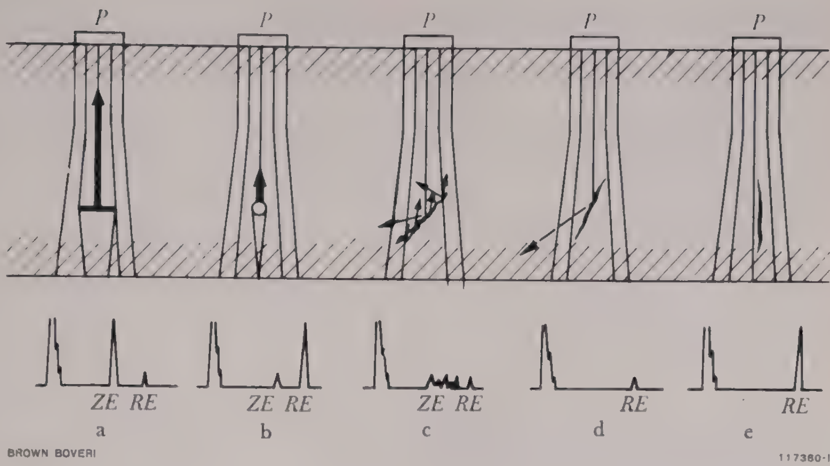


Fig. 7. – Reflection of ultrasonic waves from different kinds of surfaces (flaws)

Above: path of the beam
Below: oscillograms

ZE = Intermediate echo
RE = Back echo
P = Probe (source of sound waves)

where T = thickness of the material; D = depth of the crack; b = breadth of the crack; a = its extent in the direction of radiation; α = angle of incidence.

When D is large enough, this is true when

$$\sin \alpha \leqslant \frac{100\ b}{T}$$

Accordingly, in practice, a crack 0·014 mm wide only provides a sensitivity of about 20% with $\alpha = 0°$, and is no longer detectable with an angular deviation of 2·5°. With a width of 0·1 mm the flaw ceases to be recognizable at an angle of 15°.

Hence though it is not impossible to detect a crack or flaw in a weld by radiography, the probability is very slight. Although this state of affairs is inherently clear, and understandable, oddly enough it still gives rise to disappointments.

Ultrasonic testing

The conditions under which a material flaw will give an indication with ultrasonic waves are as follows:

- The material must permit the passage of sound waves.
- The flaw must be accessible to the sound waves, i.e. it must not be in the shadow of projecting corners, for instance (Fig. 6a), or be missed due to the deflection of the sound waves at the edge of the object (Fig. 6b).

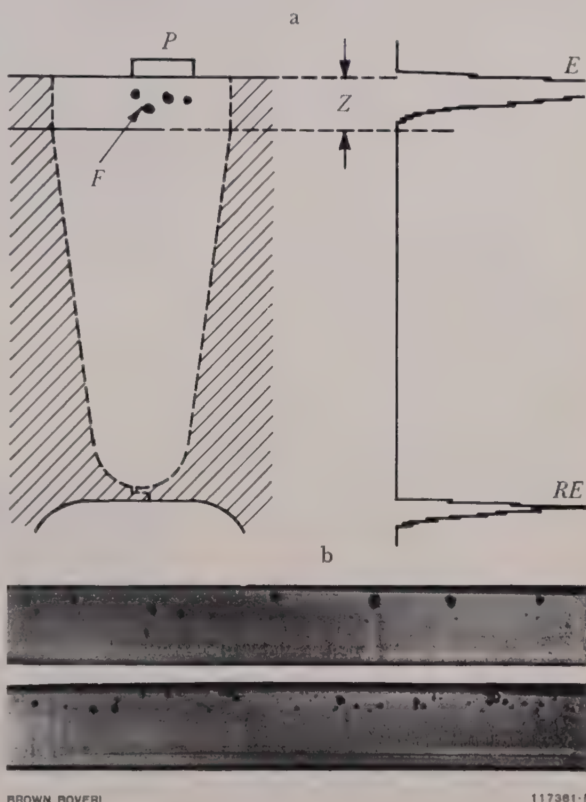


Fig. 8. – Pores within the dead zone

a: Illustrated schematically
b: Section through the porous zone

P = Probe
Z = Dead zone
F = Flaw zone
RE = Back echo
E = Incident pulse

The broken line indicates the outline of the weld.

The shape and orientation of the fault surface must be of such a nature that at least part of the arriving beam is reflected back on itself (Fig. 7 a–c), or a back echo used for a check is diminished by the flaw (Fig. 7 d). A flat flaw orientated in the direction of radiation (Fig. 7 e) cannot be detected.

Spatial flaws can generally be revealed just as well by ultrasonic waves as by radiography. An exception are the flaws situated near the surface, where they are in the dead zone of the probe. With most ordinary probes this dead zone is of the order of magnitude of one centimetre deep. It can be greatly reduced by electrical and acoustic separation of the transmitting and receiving crystal. Fig. 8 illustrates a case of severe porosity close to the surface of a machined weld, which could not be detected with an ordinary probe.

With flat flaws the effect of the width of the gap is almost negligible in comparison to radiography; also the directional sensitivity is far less pronounced. Decisive for a successful ultrasonic test of welds is, primarily, for the incidence of the sound to be as nearly per-

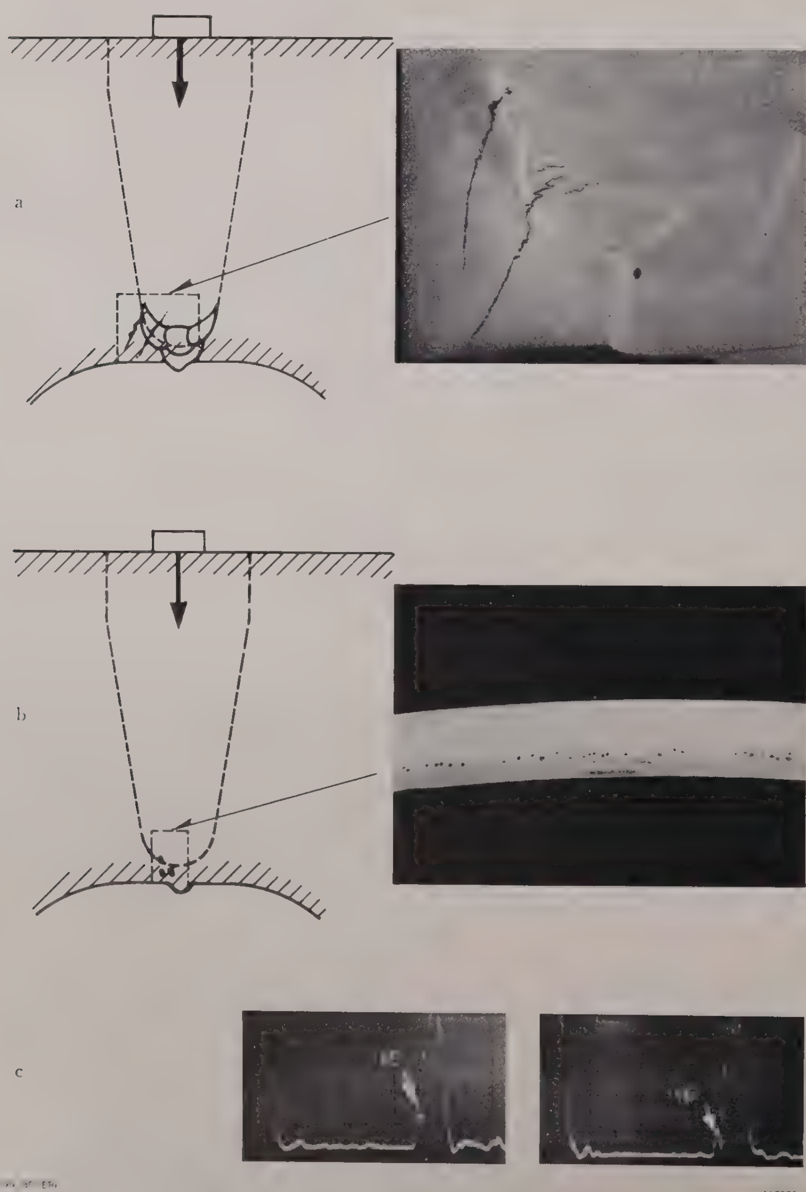


Fig. 9. – Similar ultrasonic oscillograms produced by different kinds of flaws

a: Small cracks in the bottom of the weld

b: Row of pores in the root of the weld

c: Typical ultrasonic oscillograms from both flaws (*FE* = Flaw echo)

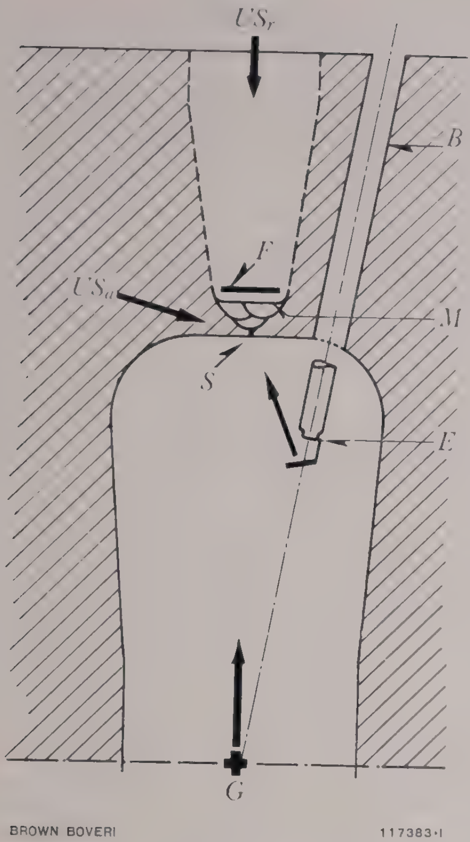


Fig. 10. – Check of fusion at the root

S = Residual crack (incomplete fusion)
B = Hole drilled for endoscope and gamma-ray source
E = Endoscope
G = Gamma-ray source
F = X-ray film
M = Magnetic-particle indication
US_r = Radial ultrasonic test, useless
US_a = Axial ultrasonic test, result good

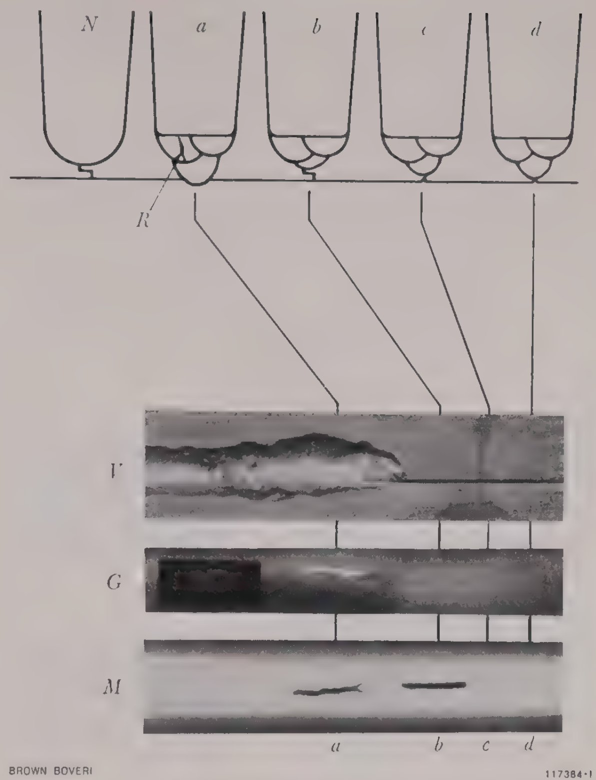


Fig. 11. – Comparison between visual, gamma-ray and magnetic test for cracks on a specimen

Zone *a*: Residual gap = 0 mm, good fusion, but crack in weld metal
Zone *b*: Residual gap = 4 mm, stepped joint not fused (double gap)
Zone *c*: Residual gap = 2 mm (single gap)
Zone *d*: Residual gap = 0·5 mm, almost completely fused
V = Visual inspection from inside
G = Gamma-ray test
M = Magnetic-particle test

pendicular to all interesting flat flaws as possible. But since the nature and magnitude of the ultrasonic indication depends on the shape and orientation of all reflecting surfaces in the cross-section of the beam, determination of the size of the flaw and its interpretation is often very difficult, when the geometry of the object only permits a limited number of incident directions.

Testing Welds in Turbine Rotors

The rotors of turbines, turbo-compressors, etc., are made of a number of sections and shaft extensions, which are joined together by peripheral welds. These seams, which may be up to 250 mm deep, have to be tested very carefully indeed. Welding is performed in two stages: first the root is welded to a depth of about 10 mm by the argon-arc process, then the rest of the seam is filled up by submerged-arc welding.

Flaws in the region of the root weld may take the form of small cracks in the bottom toe (Fig. 9a) or series of pores (Fig. 9b). When tested in the radial direction the flaws are indeed detected, but their ultrasonic oscillograms are so alike that it is almost impossible to distinguish whether one or another type of flaw is present. Only when the incident beam is at an

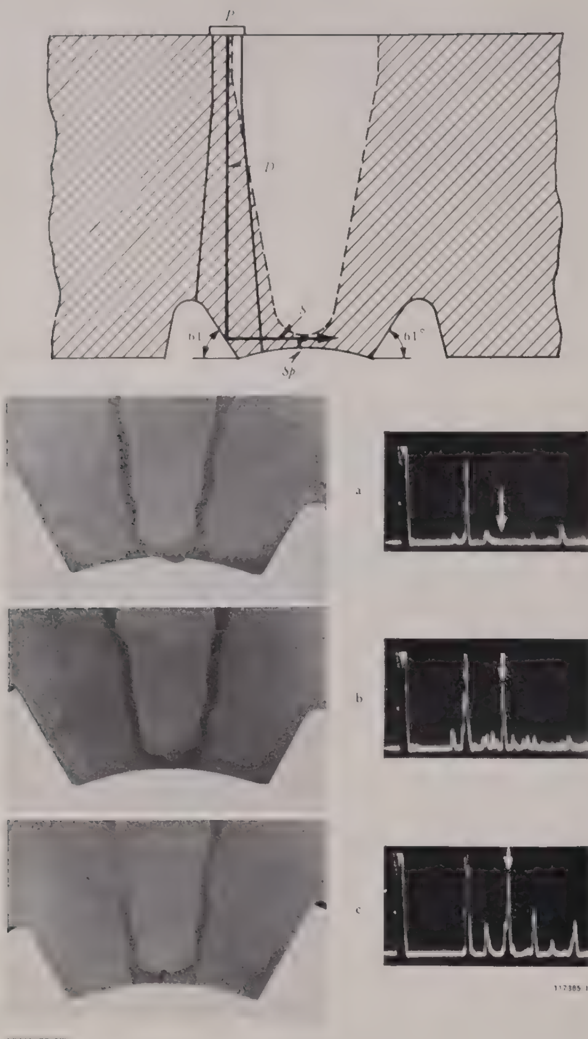


Fig. 12. – Check on the root weld with ultrasonic waves; deflection method

a: Residual gap = 0 mm (completely fused)
b: Residual gap = 2 mm
c: Residual gap = 4 mm (double gap)
P = Normal probe
D = Longitudinal wave
S = Transverse wave
Sp = Residual gap

The arrows in the oscillograms indicate the intermediate echos from the residual gap, and the points where they may be expected.

angle to the seam can the nature of the flaw be recognized more reliably.

Another kind of flaw in the root weld is when the first run was incompletely fused and an unwelded gap remains at the butt joint. Depending on the extent of fusion, this residual gap may vary in height. It can be safely avoided by careful adjustment of the welding parameters (current, arc length, welding speed).

It is impossible to detect these residual gaps by applying the sound beam radially. Better prospects are offered by radiography of the machined root weld, the source of the radiation being inserted through a hole drilled at the side (Fig. 10). The same hole may be used to introduce an endoscope, an optical instrument with lighting, by means of which the state of the weld can be inspected visually. A magnetic test on the root weld indicates the presence of the residual gaps when they are 3–4 mm or less from the surface of the seam, after machining.

In order to check the capabilities of the various methods of testing, a test weld was executed, in which a number of different flaws were deliberately caused and then examined with gamma rays, with magnetic powder and visually (Fig. 10). In this object there are the following flaws:

Zone *a*: residual gap 0 mm, well fused, but with a crack in the weld metal

Zone *b*: residual gap 4 mm, stepped root not welded

Zone *c*: residual gap 2 mm

Zone *d*: residual gap 0·5 mm

Fig. 11 shows that the visual inspection indicated the zones *b*, *c* and *d* as being incompletely fused; the radiograph only indicates zone *b* and *c*. The magnetic-particle test only yields an indication with *b*. The crack in the weld metal in *a* is not detected by the visual inspection, but is well reproduced by the radiograph and magnetic test.

The best method of detecting root flaws with ultrasonic waves is the "deflection method" illustrated in Fig. 12. Admittedly it can only be carried out when the seam has been completely welded, but it does also permit a subsequent check on the root during an overhaul. By providing reflecting surfaces, turned at an angle of 61° on either side of the joint, it is possible to deflect the sound beam through a right-angle, so that it passes through the root weld as transverse wave. It is an easy matter to detect a residual gap 0·5 mm wide by this means. Naturally the method is also sensitive to other

root flaws, especially longitudinal cracks. The machined section on either side of the root of the joint also affords relief in this respect.

With the seam depths which are currently employed, namely up to 250 mm, the only reliable method of testing the weld is by ultrasonic waves (Fig. 13). Pores, slag inclusions and faulty fusion can be detected by a normal test perpendicular to the surface of the seam. But the really unpleasant flaws are the flat radial flaws. These can be detected by allowing the waves to enter tangentially at an acute angle, in the peripheral direction; longitudinal cracks and incomplete fusion in the flanks, however, can only be detected by applying the sound at an angle to the surface and across the line of the seam.

Based on the above considerations, the following guiding rules may be quoted for the examination of rotor welds. It is advisable to test the root for cracks by the magnetic-particle method, immediately after it has been welded. Machining the root run beforehand improves the sensitivity. Cracks are easier to recognize under these conditions than later by ultrasonic testing of the finished weld. And, of course, it is far less expensive to carry out a repair at this stage. If the design permits a hole being drilled to one side of the seam, the weld can be irradiated with gamma rays and inspected with an endoscope. The final check on the weld is performed by the ultrasonic method, in three directions. It is advantageous if the whole shaft is turned down before testing. The uniform surface in this condition greatly improves the reliability of the test.

If, after thorough preliminary experiments and with correctly set welding data for such automatically executed welds, flaws are encountered very rarely in the rotor seams, a well-planned and careful test in accordance with the aspects described does provide the guarantee that these important welds will be delivered as free from flaws as possible.

Conclusions

By way of conclusion it is worth recalling certain facts which are overlooked far too often. Not every flaw in a workpiece or weld leads to failure of the affected part. It reduces its reliability though and, unfortunately, to an unknown extent. The magnitude of the reduction in reliability cannot be calculated, even when the nature, position, and size of the flaw, as well as the nature and magnitude of the stresses are known very accurately indeed. It is assumed generally that, in most cases, large, numerous flaws are more harmful than small, isolated flaws.

Depending on the consequences which may be anticipated in the event of the failure of a part, the specification may call for a very high standard of reliability, i.e. permitting as few and as small flaws as possible during the tests, or not be quite so strict when the parts are less important, and tolerate rather more, larger flaws.

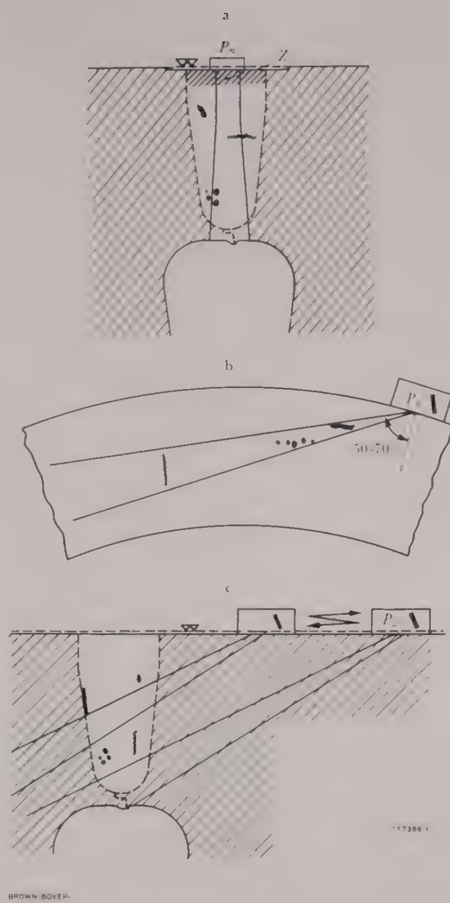


Fig. 13. – Ultrasonic test on the finished weld

a: Radial incidence from normal probe P_n (Z = dead zone)
b: Tangential incidence with angle probe P_w
c: Axial incidence across seam with angle probe P_w

The sensitivity, i.e. the size of flaws which can just be recognized, depends on the method selected for testing, while the flaw remainder, expressed as a ratio of the total number of flaws, depends on the effort put into testing (test density, time spent, number of persons engaged, etc.).

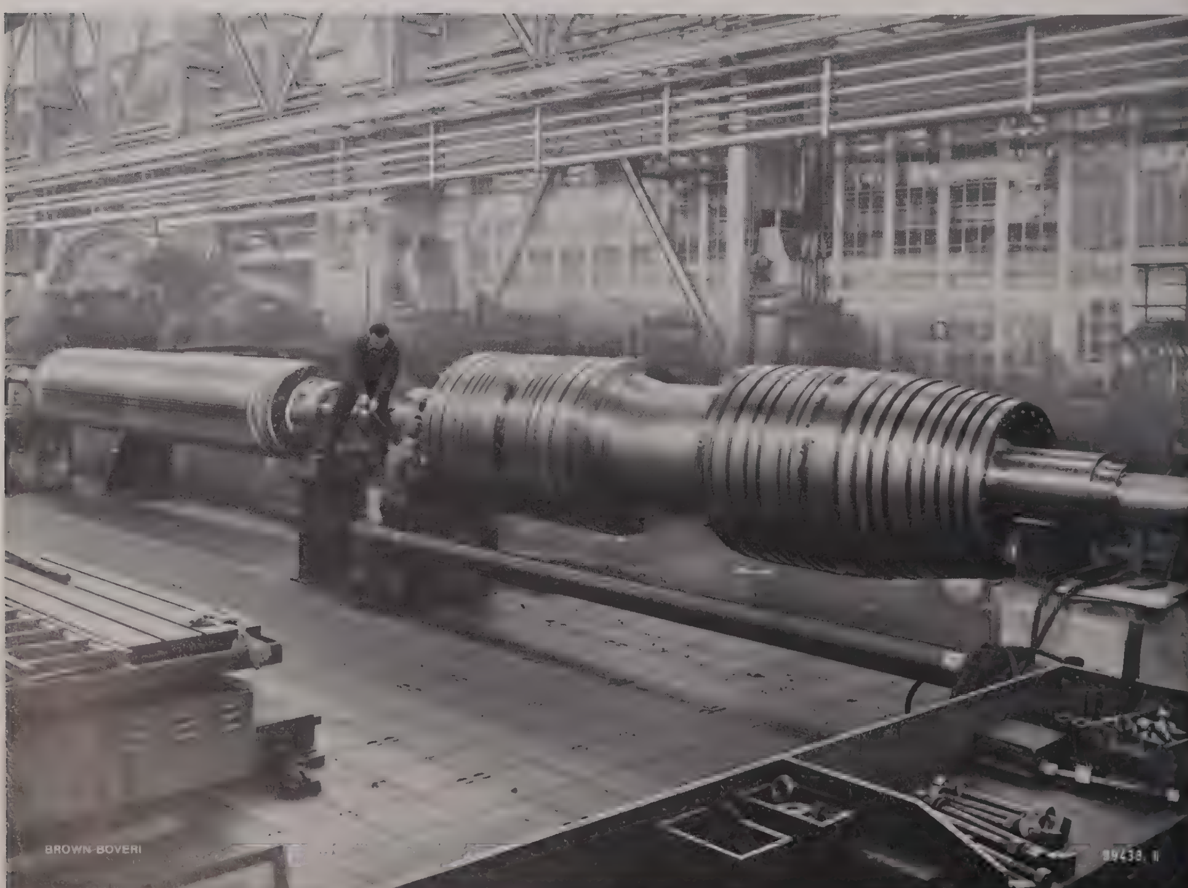
The closer the permissible limits are drawn, the higher the sensitivity specified and the smaller the remainder stipulated, the higher the cost of testing. The costs of repairs to welds also rise in a similar manner.

From these considerations we arrive at two clear conclusions:

a. Complete freedom from flaws, i.e. 100% reliability, cannot possibly be attained, even with the most intensive testing.

b. The greater the freedom from flaws and the higher the reliability specified, the greater the cost.

(KME) W. MOHR



Rotor of a steam turbine composed of welded sections

Low-pressure shaft of the turbine and the rotor of the generator belonging to a 125-MW turboset for Asnæs power station, Denmark

HEAT TREATMENT WHEN WELDING HEAT-RESISTANT STEELS CONTAINING 12% CHROMIUM

621.791.02:621.78:669.15.26

Following a review of the recommendations for welding heat-resistant steel containing 12% chromium, as given in the literature, the author refers to measurements of the mechanical properties of a steel of this kind following heat treatment at 1350 °C to form austenite, also at different temperatures in the austenitic state and during the formation of martensite. From these measurements it is evident that weld metal containing 12% Cr, when in the austenitic state, i.e. during welding with pre-heating to about 260 °C, exhibits a very high toughness as well as a low yield point. The recommended pre-heating temperatures, which are often unnecessarily high, consequently do not provide any stress relief worth mentioning, or freedom from cracking. In conclusion, a suggestion is made that, by welding in the region of martensite formation, the tempering effect of subsequent runs can be utilized, in order to reduce the tendency to crack later, when cooling.

Technological Questions

OWING to the increased use of large forgings and castings of heat-resistant steel containing 12% chromium, with Mo and V added, it proved necessary to establish the optimum conditions for welding such steels.

Twelve-percent chrome steels are known as air-hardening, i.e. even when cooled relatively slowly from the temperature at which austenite is formed, they are inclined to exhibit considerable hardening and embrittlement, with the accompanying risk of cracking [1]. One of the main problems in welding is, therefore, either to alloy the material or to carry out the heat treatment in such a manner that cracks are avoided when the weld cools.

Since the hardness of the martensite produced in the weld metal when it cools is proportional to the carbon content, the earliest electrodes to be brought out contained less than 0·1% C, and they gave a relatively soft weld metal. However, this solution proved unacceptable because, with such a low C content, the resultant steels are biphase and even after annealing may exhibit low impact strengths. The necessary minimum C content is probably of the order of 0·16%.

Steels which are not easily welded, i.e. those which tend to harden, are generally pre-heated prior to welding. The aim of this is to reduce the rate of cooling and to convert the austenitic weld metal produced on cooling into a less brittle structure than the martensite produced during rapid cooling to room temperature. If, however, in contrast to low-alloy steels, a chrome steel containing 12% Cr is welded at a pre-heating temperature above the "martensite temperature" no transformation occurs, even after holding it at this temperature for several days; the weld metal remains austenitic.

The transformation into the modification which is stable at room temperature can be effected in two different ways.

1. By heating from the pre-heating temperature to 700–750 °C without previous cooling. Then, following the precipitation of grain boundary carbides, this results in the formation of pearlite. Following this treatment the weld metal exhibits insufficient hardness and toughness values at room temperature. Although the impact strength of a material of this kind increases rapidly with temperature and reaches its maximum at about 200 °C, this procedure can hardly be adopted for severely stressed parts. The advantage of this "pearlite-forming" heat treatment is the dependable avoidance of cracks, because the conversion takes place at very high temperature.

2. By cooling and forming martensite, followed by tempering at 700–750 °C. The mechanical properties obtained by this method in the weld metal are good and almost correspond to those of the parent metal.

The drawback, though, is that during the cooling process to form martensite, severe embrittlement takes place, which can lead to cracks in large seams. In practice cooling is continued until sufficient martensite has formed. If the temperature is reduced further, the risk of cracking increases rapidly. Since this cooling process has to be uniform and checked very closely, the task of welding large objects of heat-resistant steel is always accompanied with a certain risk.

In this respect widely differing figures have been published regarding the pre-heating and cooling temperatures which have to be observed. For example, Class [2] quotes the recommendation of an electrode manufacturer, according to which the pre-heating temperature should be graduated in proportion to the thickness of the material to be welded and, up to 6 mm, for example, welding without pre-heating, from 15–20 mm heating to 250–300 °C, and between 25 and 40 mm heating to 400–450 °C. Kauhausen, Kaesmacher and Sadowski [3, 4] stipulate a fundamental pre-heating temperature of at least 400 °C (up to 500 °C) for this type of steel, in order that no transformation may take place during welding. This should be effected by reducing the temperature to 150 °C before tempering. Deep seams should also be preferably welded in several operations, cooling to 150 °C after a certain number of runs and then tempering in order to avoid unduly high stress peaks. According to a private communication from the "Bochumer Verein", the temperature of the object should be raised after welding, to 450–550 °C, with the recommendation that this temperature be held until complete equilibrium is attained, in order to reduce stresses as far as possible before the essential stress relieving.

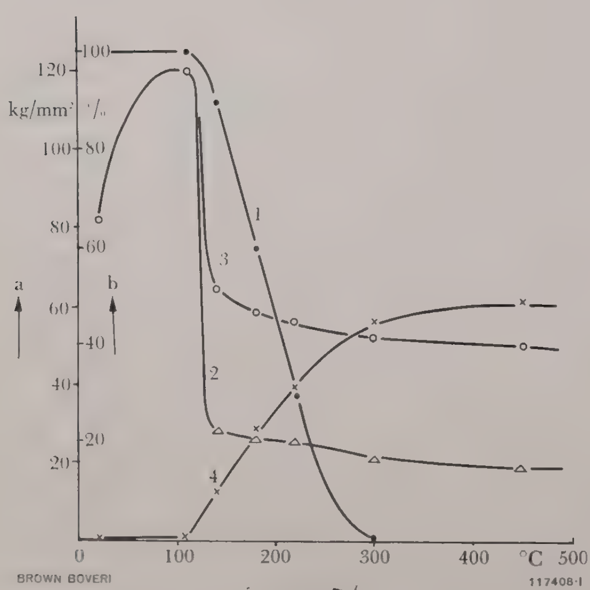


Fig. 1. – Strength, elongation and martensite content of 12% Cr steel at different temperatures following austenitic treatment at 1350 °C

a = Yield point in kg/mm², tensile strength in kg/mm², elongation in %
b = Martensite content in %
t = Test temperature in °C
1 = Martensite content
2 = Yield point
3 = Tensile strength
4 = Elongation

Tests in the Metallurgical Laboratory

Preliminary tests

With welded joints 100 mm or more in depth on highly tempered objects, where shrinkage is very difficult, such as occur in sectional steam-turbine rotors, a large proportion of the shrinkage strains must be taken up by the weld metal. Cracks occur when the deformation capacity of the weld metal is exceeded. Consequently the toughness and strength of a 12% chrome steel were measured at the temperatures experienced from the moment of solidification till the completion of the heat treatment.

Since such an investigation is difficult to perform on weld metal and, compared with a rolled product having the same analysis, no great diversity may be expected, a rolled material with the following composition was chosen as initial material:

C %	Cr %	Ni %	Mo %	V %
0·19	11·9	0·68	1·1	0·37

First of all, the temperatures at which martensite formation begins and ends, and the percentages of martensite formed at the intermediate temperatures were

determined by a dilatometer. Then specimens 10 mm in diameter and 100 mm effective length, subsequently used for tensile strength tests, were heated to 1350 °C for two minutes to produce austenite, cooled with a blast of compressed air to 500 °C, and tested to fracture at the various temperatures of interest. The measured values, such as the yield point, tensile strength and elongation are plotted as a function of the temperature and the respective approximate martensite content in Fig. 1.

From these results it can be seen that in the austenitic state this steel exhibits excellent toughness properties, even at relatively low temperatures. Also remarkable is the low yield point, varying little with temperature. During the formation of martensite this only increases slowly. Obviously it is determined by the austenite still present and, following complete transformation, it jumps abruptly to values of the same order as the tensile strength. The elongation decreases continuously with increasing martensite content, becoming practically zero at 100% martensite. At quite low martensite contents, despite existing elongation, a certain sensitivity to impact can be detected, as may be seen in Fig. 2.

The tensile strength increases during cooling. At about 100% martensite content it reaches a maximum, diminishing again with a further decrease in temperature owing to the apparent increasing notch sensitivity. This reduction is naturally dependent on existing defects.

Thus if a weld is executed on a 12% chrome steel with electrodes of the same kind and at a pre-heating temperature above the martensite (Ms) point, i.e. between 250 and 280 °C, it is hardly possible, even with strong restraint, for the stresses in the seam to rise above the yield point of 20 kg/mm² of the still austenitic material. The deformation caused by shrinkage is completely absorbed by the soft and tough weld metal. When, following welding, the temperature drops, and provided sufficient martensite has been formed, the yield point rises above that of the unaffected parent metal which now has to absorb the greater part of subsequent deformation. If, due to excessive cooling, the toughness of the seam drops so far that defects in the weld metal, such as slag inclusions, pores, etc., become effective, i.e. the strength diminishes, the risk of cracking increases. Cracking of the very brittle weld metal due to cooling too far is therefore influenced by the yield point, as well as by the shape and dimensions (restraint) of the welded parts, the number and sharpness of existing defects, and by possible additional stresses produced by manipulating the parts in this critical state.

Fig. 2. – Tensile test specimens after austenitic treatment, tested at 110, 140, 180, 220 and 300 °C, with a rod in the initial state (left) for comparison

Half natural size.

The choice of the pre-heating temperature, provided this is above the Ms point, hardly affects the susceptibility to cracking. Also excessively high pre-heating temperatures—up to 550 °C have been suggested—cannot achieve any marked improvement in the toughness, nor reduce the stress in the soft and tough austenitic weld metal. No appreciable reduction in the stresses can be expected from keeping the temperature constant at 500 °C for several hours after welding, when the stresses do not exceed 20 kg/mm².

Fig. 3. – Section through an automatically welded seam 105 mm deep. 12% Cr weld metal with additive of Mo and V

Natural size.

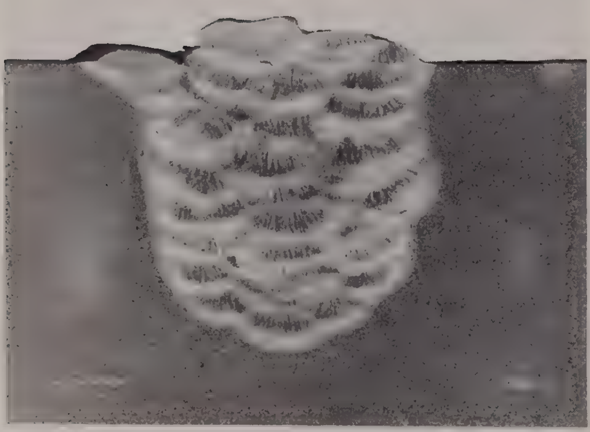


Fig. 4. – Seam welded at a pre-heating temperature of 150 °C

Natural size.

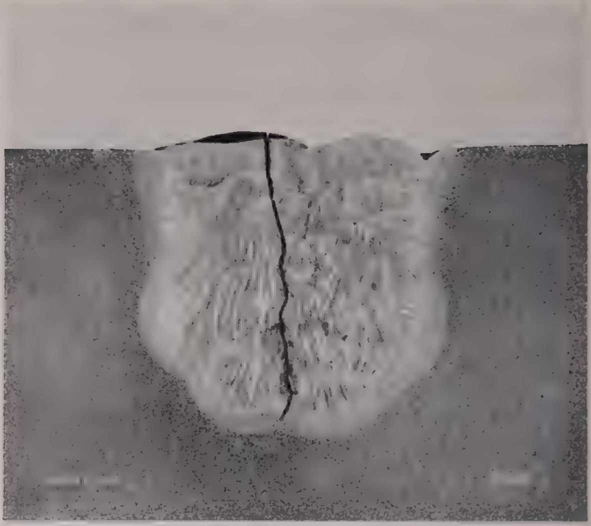


Fig. 5. – Seam welded at a pre-heating temperature of 350 °C

Natural size.

Welding tests

To confirm the observations made hitherto, seams 100 mm deep were welded by submerged-arc welding in a steam turbine rotor of 12% chrome steel, using electrodes of the same kind, in a single operation (Fig. 3). The pre-heating temperature was 325 °C. Following welding, the seam was allowed to cool to 125 °C and immediately tempered at 720 °C.

The seams proved to contain no cracks and possessed almost the same mechanical properties as the forgings.

Cooling deep seams to produce martensite is of course never absolutely without risk and an obvious move is to try to minimize the effects of embrittlement during cooling. Consequently the suggestion was made that deep seams should be welded in several operations, cooling and tempering being performed after a number of runs have been welded.

An optimum reduction in the volume of weld metal which has to be converted can be obtained if the pre-heating temperature is made less than the Ms point, for instance about 150 °C. In this case each run turns into martensite to a certain extent. This procedure also exhibits the great advantage that the martensite produced in each run is tempered by the succeeding run. Later, when cooled to convert the rest of the austenite,

the weld metal will not become so brittle because part of it already consists of tempered martensite.

Experiments, though carried out at first on seams only 40 mm deep, prove that such seams can actually be cooled down to room temperature without cracking, whereas identical seams welded at pre-heating temperatures of 300 or 500 °C cracked when cooled down to room temperature (see Fig. 4 and 5). After cooling, the average hardness of the seam welded at 150 °C was of the order of 80–100 Vickers units less than that of the seams welded at 300 and 500 °C. Following tempering at 720 °C this difference was no longer apparent.

Of course, before this method can be adopted for deeper seams it will be necessary to carry out tests. In practice it will probably be difficult too to keep within the close temperature limits of 150–180 °C, depending on the size of the objects, the manner in which they are heated to the pre-heating temperature and the facilities for measuring the temperature.

Optimum pre-heating temperatures when welding below the Ms point, or cooling temperatures when welding above it, can obviously only be laid down when exact information is available regarding the slight variation in transformation characteristics of the weld metal from charge to charge.

(KME) G. FABER

Bibliography

[1] W. PETER and W. MATZ: Das Umwandlungsverhalten von Stählen mit 12 bis 14% Cr. Arch. Eisenhüttenwesen 1957, Vol. 28, No. 12, p. 807.

[2] J. CLASS: Kennzeichnende Eigentümlichkeiten des warmfesten 12%igen Chromstahls und Aussichten für seine Einführung in den Kesselbau. Mitt. Vereinig. Grosskesselbesitzer 1959, Vol. 58, p. 38.

[3] E. KAUHAUSEN, P. KAESMACHER: Die Metallurgie des Schweissens warmfester 12%iger Cr+Mo–V–W legierter Stähle. Schweissen und Schneiden 1957, Vol. 9, No. 9, p. 414–9.

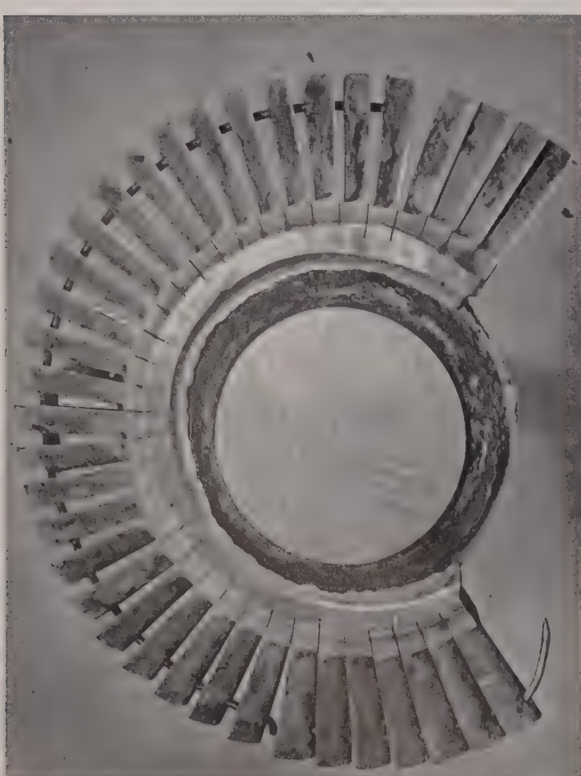
[4] E. KAUHAUSEN, P. KAESMACHER, S. SADOWSKI: Probleme der Schweissung an warmfesten Stählen. Werkstatt und Betrieb 1960, Vol. 93, No. 6, p. 289.

PROBLEMS OF WELDING STEELS OF DIFFERENT KINDS USED IN THERMAL MACHINES

621.791:669.15-194.2/.3

From practical experience numerous cases are known of difficulties which have arisen out of welding high and low-alloy steels for operation at high temperatures, owing to decarburization and recrystallization zones leading to local weakening of the joints. The present article, taking as example a joint between 12% chrome steel with a low-alloy MoV steel, shows how the conditions vary according to the composition of the weld metal, and indicates which variant can be expected to give the best performance in service.

IN WELDED joints between high and low-alloy steels used in thermal machines, it is possible for a decarburized and recrystallized zone to occur in the low-alloy component, immediately adjacent to the fusion zone



BROWN BOVERI 117355 I

Fig. 1. – Impeller of an exhaust-gas turbocharger which became defective in operation

which, when subjected to creep stress, may result in local weakening. Fig. 1 shows an example of an impeller of an exhaust-gas turbocharger in CrNiMo steel on to which the austenitic blades were welded, which became defective in service at the junction between the disc material and the austenitic weld metal. Fig. 2 shows the corresponding structure, with the end of the crack and the recrystallized zone in the CrNiMo steel. The same phenomenon also appears in other material combinations and can be artificially produced by heat treatment without the application of stresses at the same time. Fig. 3 shows a similar case in the transition zone between 12% chrome-steel and ordinary carbon steel. In this case local decarburization occurred by diffusion at high temperature, followed by recrystallization in the C-impoverished zone. Here the carbon diffused from the boundary zone of the low-alloy steel into the more highly alloyed steel, in which the carbon is more soluble. The phenomenon varies with the local carbon concentration, the solubility of the carbon, the nature and quantity of elements forming carbides in the two steels, the rate of diffusion, the temperature and time. Hence the problem is very complex, but the hazard can be reduced by the following three measures.

a. Reducing the gradients of the C activities in the fusion zone by employing weld metals with graduated contents of carbon and elements forming carbides.

b. Strengthening the bonding of the carbon in the lower alloyed steel by the addition of powerful carbide formers, such as titanium or niobium.

c. Preventing the diffusion by employing a weld metal with a very slow diffusion rate.

Attention must, however, be paid to the fact that the resistance to heat and the ductility must not be ad-

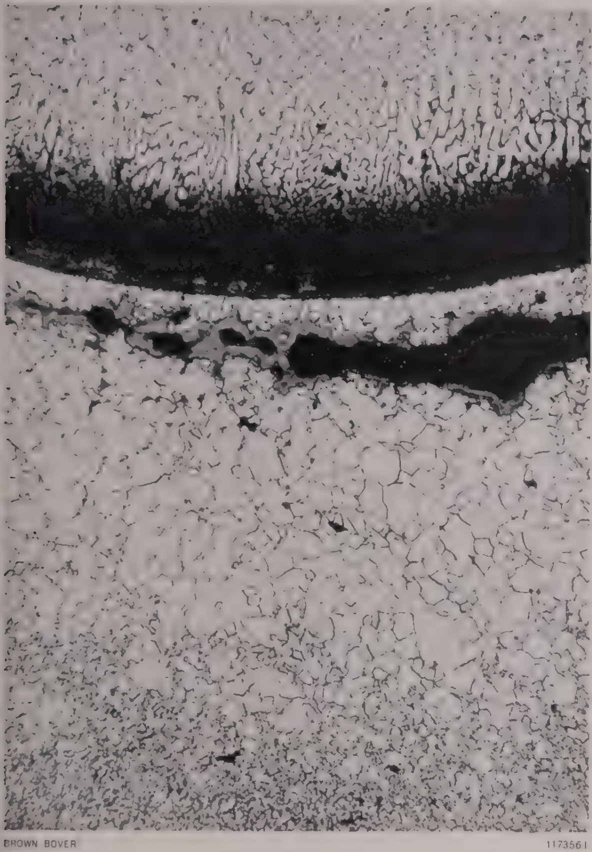


Fig. 2. – Micrograph through the decarburized and recrystallized zone in CrNiMo steel adjacent to the austenitic weld metal (top)

Enlargement × 100

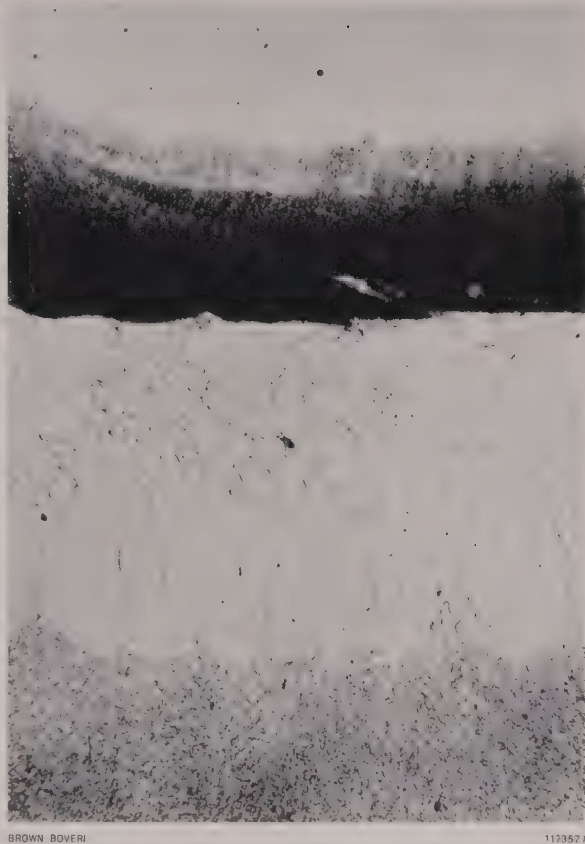


Fig. 3. – Decarburized and recrystallized zone in ordinary mild steel adjacent to 12% Cr steel (top)

Enlargement × 100

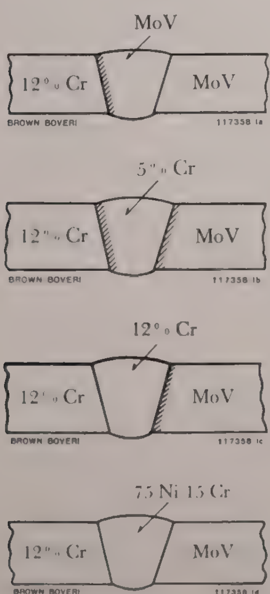


Fig. 4. – Diagrams illustrating the four weld variants investigated (see table overleaf)

versely affected by any of the above measures, that non-cracking welds must be obtainable at an economical cost, and that the coefficients of expansion of the individual components must be similar in order to avoid undue internal stresses. Therefore it is hardly possible to find an optimum solution for all material combinations; the remarks that follow will thus concentrate on combinations between 12% chrome-steel with a low-alloyed MoV or CrMoV steel, which are frequently employed in the manufacture of steam turbines.

The Variants Investigated

The four investigated variants of welded joints between heat-resistant steel (12% chromium) and low-alloyed MoV steel are illustrated schematically in Fig. 4. Of these, the variants 1 and 3 have the full gradient of

the C activity in one step, whereas 2 has the activity divided into two steps. It is therefore more probable that decarburization and recrystallization zones would occur in variants 1 and 3, than in 2. In variant 4 the diffusion is severely hindered by using a weld metal with a high nickel content, so that here the risk of decarburization is smallest. This variant, however, has the disadvantage of producing very indefinite mixing zones between the weld metal and the parent material, the composition and coefficients of expansion of which are very difficult to estimate. Nevertheless, all four variants were welded without great difficulty at 300 to 450 °C and, after cooling to 100–150 °C followed by heat treatment to 660–680 °C, were found to be free from cracks. Tests on the various specimens (slabs 300 × 300 × 50 mm) yielded the following results.

Measurements

1. Chemical Analyses

	C %	Si %	Mn %	Cr %	Ni %	Mo %	W %	V %	Nb %
12 % chrome-steel	0.15	0.33	0.72	11.8	<0.3	0.72	—	0.39	0.36
MoV steel	0.13	0.36	0.49	0.30	<0.2	0.72	—	0.35	—
Weld metal 1	0.11	0.39	0.53	0.28	<0.2	0.74	—	0.30	—
Weld metal 2	0.16	0.27	0.48	4.60	0.63	0.62	—	0.45	—
Weld metal 3	0.17	0.29	0.27	12.8	<0.2	0.96	0.41	0.38	—
Weld metal 4	0.12	0.53	2.90	15.5	75.8	1.30	—	—	2.20

Specimen for analysis of the weld metal taken from the final run.

2. Tensile Tests on Parallel Bars at Right-Angles to the Seam at 20 °C

Variant	Yield point kg/mm²	Tensile strength kg/mm²	Elongation %	Fracture
1	57.5	68.7	7.7	in weld metal
2	54.9	64.0	13.9	in MoV steel
	52.2	63.8	13.5	in MoV steel
3	57.4	71.4	3.2	in MoV steel
	60.5	71.8	2.8	in MoV steel
4	52.1	72.7	11.0	in weld metal
	49.8	69.0	6.6	in fusion zone with MoV steel

3. Impact Tests on VSM Specimens

Variant	Position of notch / Toughness in kgm/cm²				
	12 % Cr steel	Fusion zone with Cr steel	Weld metal	Fusion zone with MoV steel	MoV steel
1	6.2	2.0/6.3	12.0/16.8	9.2/16.3	15.4
2	7.7	2.1/3.1	16.1/20.0	12.3/14.7	13.1
3	8.7	10.4/9.6	9.3/11.1	5.3/ 7.2	12.0
4	4.9	6.4/6.3	11.7/13.3	6.4/ 7.5	12.6

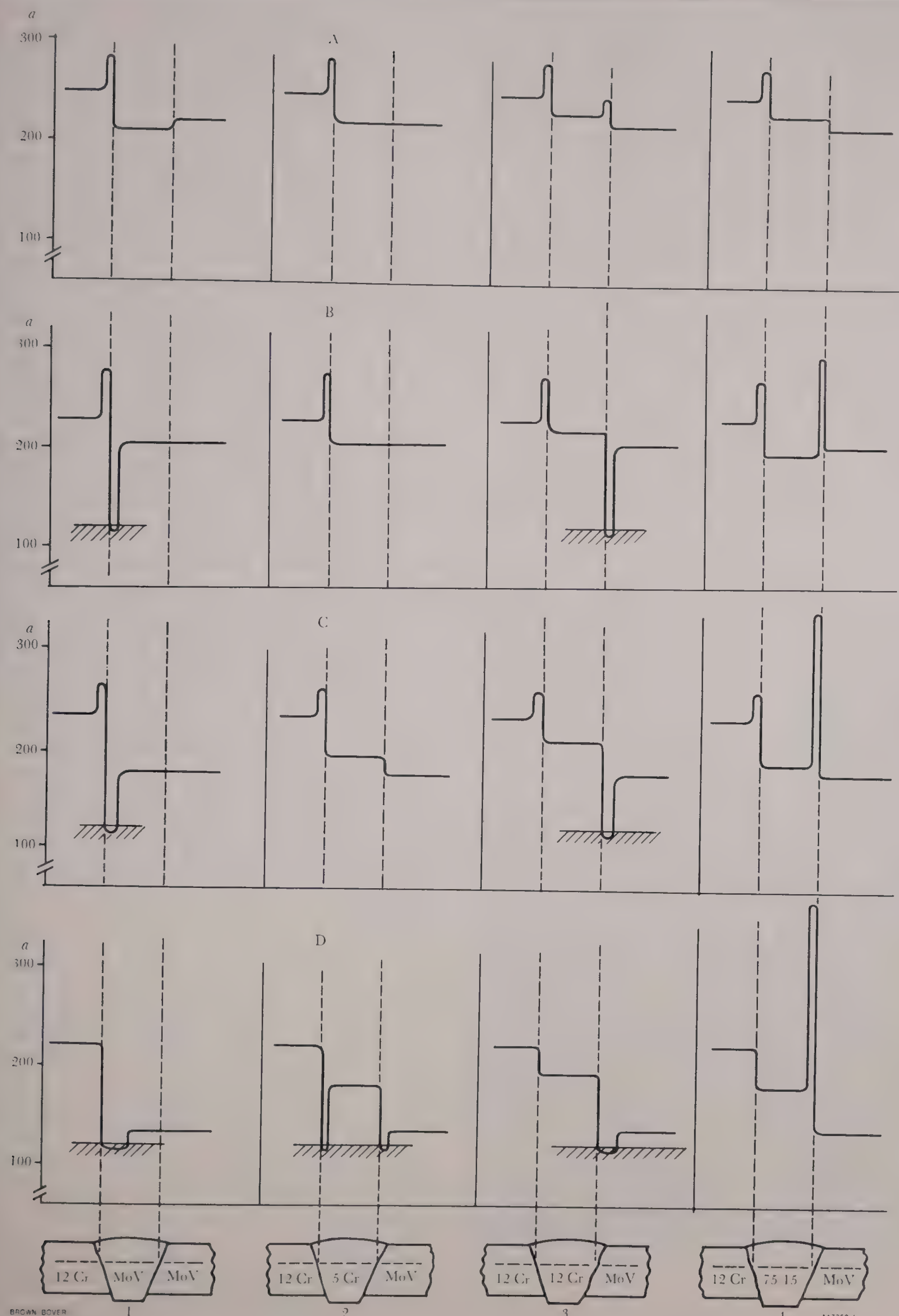


Fig. 5. – Hardness of the annealing specimens a= Hardness in kg/mm² B: after 1000 h at 600 °C D: after 1000 h at 700 °C
A: Initial state C: after 1000 h at 650 °C 1–4 Variants (as per Fig. 4)

From the above figures it is apparent that all four types of welds can be used to produce joints free from cracks, and also that in their initial state the joints exhibit quite satisfactory mechanical properties. To assess their tendency to decarburize, annealing tests were carried out, followed by hardness measurements and examination of the structure, the mechanical effect of the decarburization zones being checked by creep tests.

Annealing Tests

The most important results obtained from these tests, which involve heat treatment without stress, are illustrated in Fig. 5, in which the hardness measurements are plotted for the initial state and after heat treatment for 1000 h at 600, 650 and 700 °C, respectively. It will be observed that variants 1 and 3 begin to exhibit very low hardness values (110–130 kg/mm²) already after 1000 h at 600 °C, whereas variant 2 only reaches this state after 100 h at 700 °C. By dividing up the gradient of the C activities, the hazard was spread between two points, and its effect reduced accordingly. Finally, with variant 4, owing to the diffusion of the C being hindered by the high nickel content of the weld metal, no local reduction in hardness was detected, even after 1000 h at 700 °C. On the other hand, in the mixing zone of the weld metal severe local hardening was encountered, the maximum value of which rises to over 340 kg/mm² with increasing temperature. Whether diffusion effects have anything to do with this has not been determined yet. To judge by the position of the hardened zone, however, it appears quite feasible and would thus indicate that even this variant is not completely immune from decarburized zones.

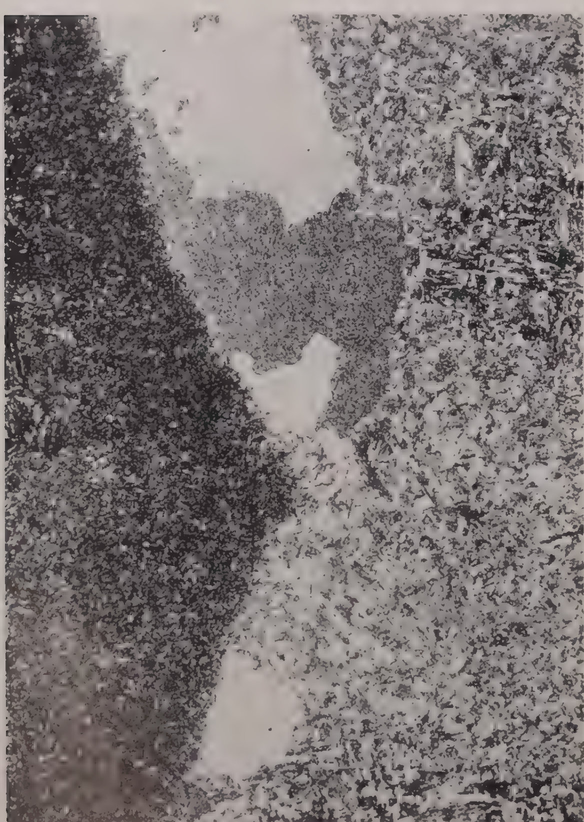


Fig. 6. – Decarburized and recrystallized zone in MoV weld metal

on the right, next to the fusion zone with the 12% Cr steel (left) after heating at 600 °C for 1000 h. Enlargement × 100.

Examination of the structure of isolated specimens confirmed that the decarburization and recrystallization zones may always be found when local hardness values of about 120 kg/mm² are measured. A MoV steel containing 0·13% C can hardly be expected to drop to such a low value without decarburization. A typical example of decarburized and recrystallized zone, as found in variant 1 after 1000 h at 600 °C is depicted in Fig. 6.

If an attempt is made to transfer these results to longer fracture periods at lower temperatures, this is made easiest by assuming that the same diffusion laws apply to loss of hardness by MoV steel as to decarburization and recrystallization. The softening of specimens of MoV steel used for the annealing tests can be measured quite easily and, with the aid of hardness measurements on the heads of creep test bars, yielded the family of curves in Fig. 7. If the points at which recrystallization commences are plotted in these curves, and parallel curves are drawn, a limiting temperature is obtained at which the phenomenon may be expected after a definite time. Expressed numerically after, say 10^5 h (about 11 years), these temperatures are:

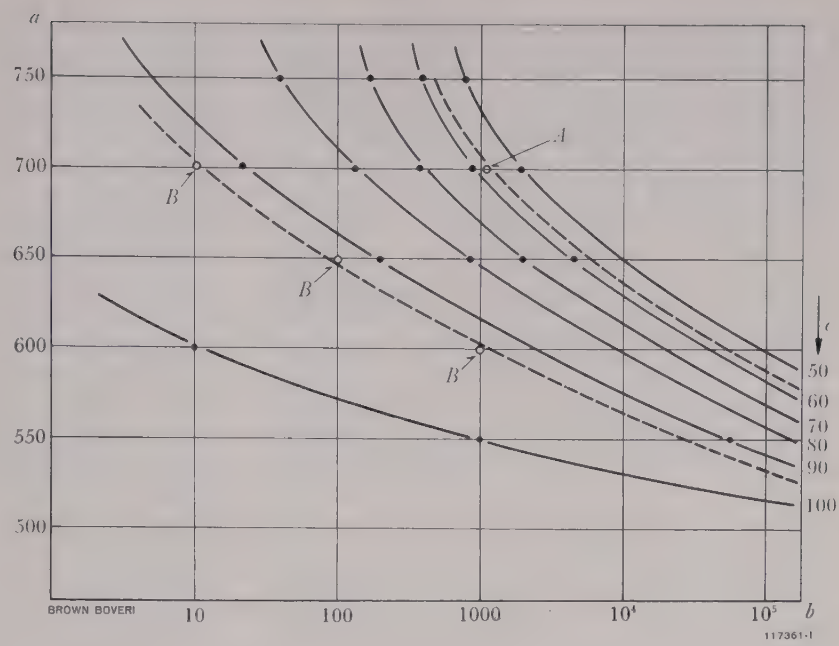


Fig. 7. – Curves showing the softening of MoV steel and the recrystallization limit for the variants 1, 2 and 3

a = Annealing temperature in °C
b = Time in h (log scale)
c = % of initial hardness in MoV steel

A: Start of recrystallization in variant 2 (weld metal with 5% Cr)

B: Start of recrystallization in variants 1 and 3 (MoV and 12% Cr weld metal)

Variant 1	appr. 530 °C
Variant 2	appr. 590 °C
Variant 3	appr. 530 °C
Variant 4	appr. 600 °C

From which it can be seen that the variants 1 and 3 may be disregarded for a large number of applications.

Creep Tests

The specimens for the creep tests were taken at right-angles to the welded joints and tested at 550 °C. They yielded the fracture curves in Fig. 8. Although the test times thereby attained were not really very long and, according to Fig. 7, recrystallization zones ought not to be encountered, the variants 1 and 3 exhibit quite an appreciable drop in the curves after about only 1000 h. The curve for variant 4 is almost as steep, although in this case there can be no question of decarburization. Most favourable for long times is variant 2. This may be explained by looking at the macrographs of the fractured creep test specimens (Fig. 9–12), in which it is quite clear that tough fractures in the weld metal only occurred with variant 2 (elongation on fracture 17–24%), whereas all the other specimens became defective as the result of brittle fracture in the fusion zones (elongation 1–8%). Consequently these are all premature fractures due to locally weakened or stressed zones, freedom from which only appears to be exhibited by the specimens of variant 2.

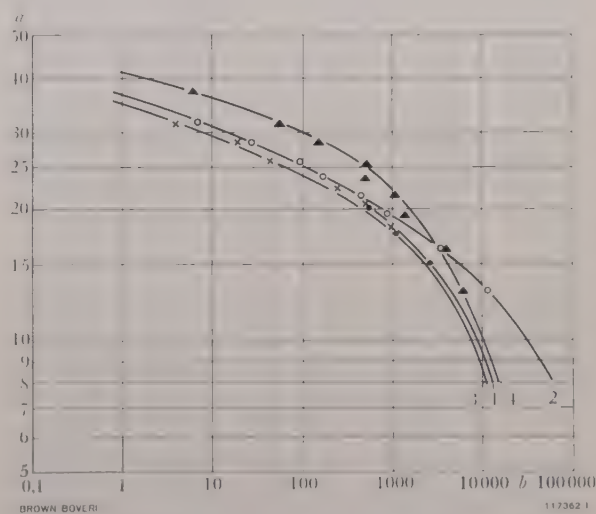
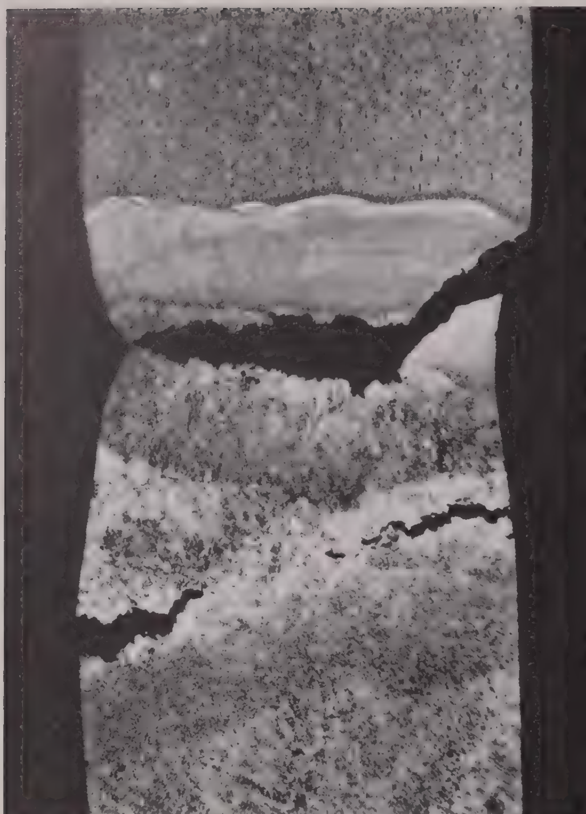
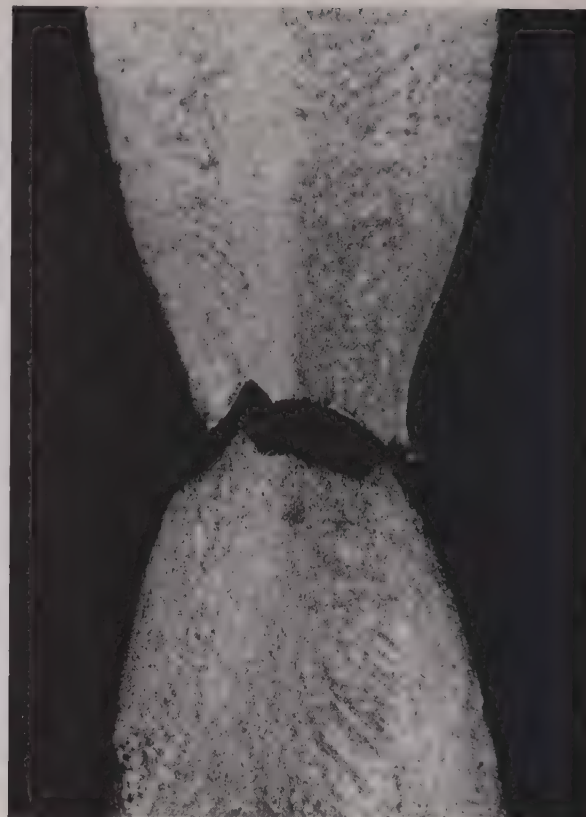


Fig. 8. – Creep curves for 550 °C

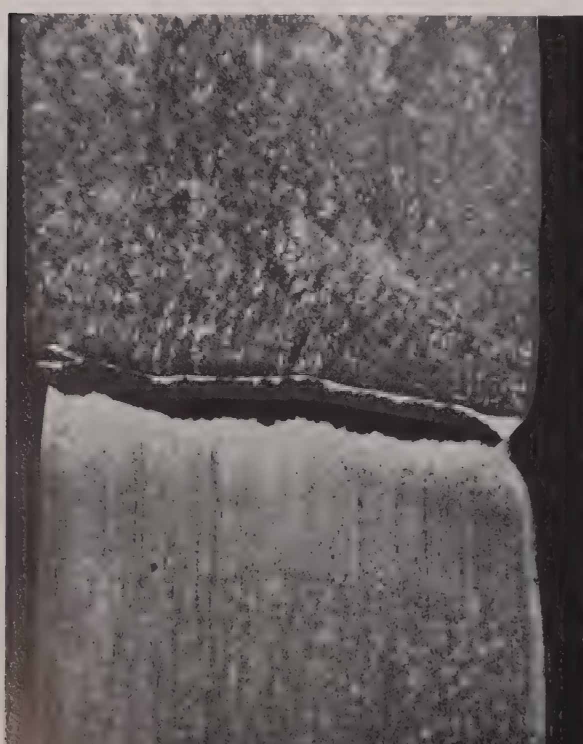
a = Stress in kg/mm²
b = Time till fracture in h (log scale)
1–4 = Variants



BROWN BOVERI 117363.I



BROWN BOVERI 117364.I



117365.I

BROWN BOVERI 117366.I

Fig. 9 (above left). – Specimen of variant 1 after creep test

Tension = 15·0 kg/mm² at 550 °C
Fracture after 2877 h with 4·2 % elongation
Enlargement × 7

Fig. 10 (above right). – Specimen of variant 2 after creep test

Tension = 16·2 kg/mm² at 550 °C
Fracture after 3467 h with 16·7 % elongation
Enlargement × 7

Fig. 11 (below left). – Specimen of variant 3 after creep test

Tension = 18·2 kg/mm² at 550 °C
Fracture after 970 h with 3·1 % elongation
Enlargement × 7

Fig. 12 (below right). – Specimen of variant 4 after creep test

Tension = 16·0 kg/mm² at 550 °C
Fracture after 3683 h with 1·1 % elongation
Enlargement × 7

Conclusions

Reviewing these results, it is evident that none of the four welding variants is completely satisfactory when heat-resistant steel containing 12% chromium has to be joined to low-alloy MoV steel. If welding is performed with a low-alloy electrode (variant 1) or an electrode containing 12% Cr (variant 3), the decarburization and recrystallization zone occurs at quite a low operating temperature (appr. 530 °C), or after stress relieving it may even appear after 10 h at 700 °C. Such joints therefore have a poor creep strength. If welding is carried out with a high-alloy electrode containing nickel, on the other hand, decarburization is largely prevented by the hindrance of carbon diffusion, but some very hard zones are produced at the edges of the weld metal, leading to premature brittle fracture when subjected to creep stresses.

The most favourable variant is 2, in which the gradient of C activities was graduated by using a 5% Cr weld metal. By this means it is possible to retard the formation of a determinable decarburization and recrystallization zone to such an extent that an operating temperature of 580–590 °C is permissible for up to 10^5 hours. During the creep test at 550 °C this kind of joint yielded a fracture curve comparable with that of the MoV steel, and up to 5000 h only tough fractures were found in the weld metal.

(KME) R. MONTANDON

PROGRAMME-CONTROLLED HIGH-CAPACITY SPOT WELDING MACHINE WITH A MOTOR-DRIVEN BEAM

621.791.763.1.037

This article describes a new design of spot welding machine, specially devised to handle workpieces of large area. This machine, which possesses a number of remarkable features, is ideal for the fabrication of coachwork for railway carriages and buses.

WHEN workpieces covering a large area have to be welded, the employment of spot welding machines has to overcome a number of difficulties. When the workpiece is transported between the electrodes, it can easily become distorted, which necessitates subsequent straightening. The movement of the relatively large objects, such as the whole side of a carriage with all its clamping devices, and accurately controlling the electrodes to the desired spot, is cumbersome and wastes a great deal of time. Changes in the current when large masses of magnetic material are introduced into the variable throat area of the machine cannot be corrected quickly with simple means.

All these difficulties were taken into account in the design of the new Brown Boveri spot welding machine type PDT 30 U (Fig. 1). Here, for the first time, it becomes possible to differentiate between the feed movements of the machine up to a fully programmed working sequence. Compared with earlier models, this new machine offers a far wider range of possible applications.

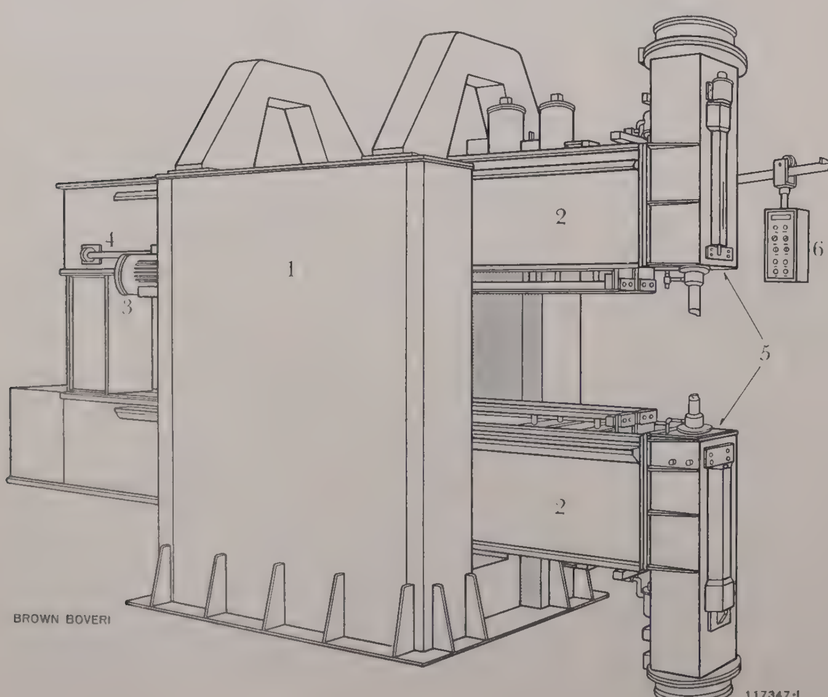


Fig. 1. – Programme-controlled high-capacity spot welding machine type PDT 30 U with travelling beam

intended for welding workpieces covering large areas.

1 = Side supports
2 = Beam propelled by an electric motor
3 = Motor
4 = Drive spindle
5 = Hydraulic-pneumatic electrode actuators
6 = Pendant control unit on pivoted arm

The guiding principle behind the design was that the workpiece should remain at rest during the entire welding process, thus reducing the workshop floor-space required. The upper and lower arms of the beam are therefore firmly fastened to each other and move in and out together. With a total travel of 150 cm the maximum extension amounts to 180 cm, and the electrodes can be controlled to spots with an accuracy of 0·5 mm.

High electric power and electrode force allow the machine to weld with extremely short times. This helps to keep distortion of the workpiece small because the local heat development is not unduly high. Furthermore the electrical losses due to heat conduction by the workpiece are very low.

The maximum current attainable is 100 kA for light alloys. Consequently the maximum power is very high, amounting to 1000 kVA, and the load is spread over the three phases. The inductance of the secondary circuit is unaffected by the movement of the two arms because the machine transformer is permanently mounted between the beams and moves with them.

The travel of the two electrodes, which at 36 cm may be regarded as extraordinarily large, permits deeply recessed workpieces to be welded. The electrode travel is variable in both cases, the ranges overlapping to such an extent that the height of the work may be within ± 180 mm of a centre-line. Presetting is performed by hydraulic means, while the electrode force is produced pneumatically.

The design of the gearing for controlling the feed motion of the beam complies with the requirements for optimum feed speed. It is assumed that the machine will have to weld 30 spots per minute at intervals of 30 mm. Allowing 1 second per spot—the full cycle comprising the squeeze time, weld time and hold time—a normal feed rate of 180 cm/min is obtained. This is achieved by a pole-changing motor rated 4·7/7 kW at 750/1500 rev/min, which is kept permanently running when the machine is in service. In the normal gear this motor moves the beam, weighing altogether 8 t, at 180 cm/min and in the high-speed gear at 360 cm/min. A pair of multiple-disc clutches and brakes producing a torque of 25 mkg control starting and stopping. With only a few push-buttons and a system of contactor control for the pole-changing motor the electrodes can be steered to any point along a single coordinate.

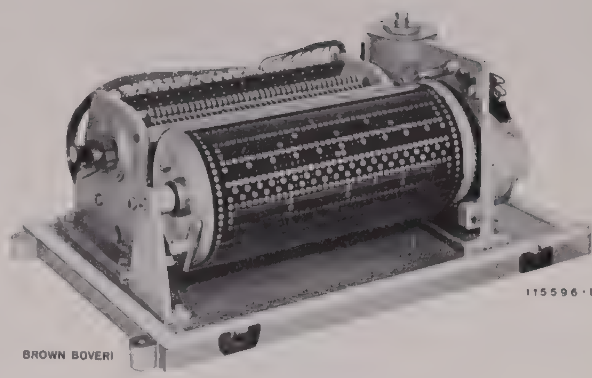


Fig. 2. – Programmer

With relatively little additional outlay the machine can be extended to cope with semi-automatic step-by-step operation. In this case, after selecting the desired direction of travel and the distance between spots, the beam is advanced by the set distance spot for spot, simply by pressing the "Weld" button. The length of the welded joint may then amount to the full travel of the beam. When operating in this manner the welding and feed controls automatically function alternately.

Full advantage of the capacity of the installation can, however, be taken by fully programming its operation, thereby noticeably reducing idle times. The main element of the positioning and programming system is a programmer (Fig. 2) developed by Brown Boveri for simple programmes. With it 40 items of information, comprising positional and switching instructions, can be introduced simultaneously into the control system of the welding machine. This programme then includes all operational functions of the installation, such as normal feed rate, high-speed traverse, automatic control of the electrode travel to enable them to clear stiffeners on the workpiece (adjustable in ten steps), all positions for steering to spots at intervals of 5 mm over a total distance of 18 m, as well as the desired spot spacing in steps of 5 mm within a range of 20–150 mm.

From the equipment aspect the programming system was developed in accordance with the principles already adopted with machine tools. But it is only possible to

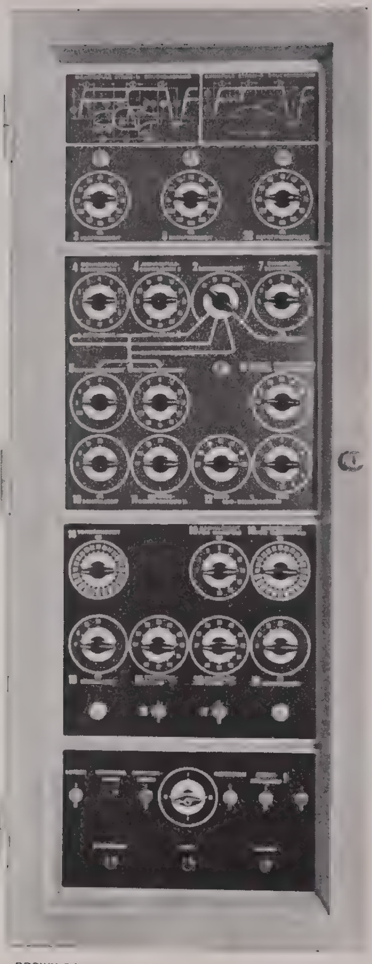


Fig. 3. – Control board for three-phase control of the high-capacity spot welding machine

Fig. 4. – Pendant control unit of the spot welding machine

make full use of its possibilities when the working sequence is so arranged that all spot welds situated in one plane are covered. In order to reach not only the points in the direction of travel of the beam, but also all points along the workpiece, the whole machine is mounted on an undercarriage, the drive and gearing of which correspond to those of the beam.

The welding data are selected on a three-phase control unit (Fig. 3), on which the following can be preset:

Squeeze time	0·2–2 s
Preheat time	0·2–6 s
Preheat current	30–60%
Weld time	in pulses of 0·02–0·1 s Consecutive pulses with alternating polarity can be strung together up to 2 s total
Welding current	30–100%
Post-heat time	0·2–6 s
Post-heat current	30–60%
Forge time	0·2–10 s
Off time	0·2–2 s or dependent on feed rate
Slope control and Pressure programme	included

The pressure programme operates at low pressure during the squeeze time and weld time, and at increased pressure during the forge time, the starting time being pre-selected and, possibly, during the weld time itself. The actual welding functions are controlled from a cabinet separate from the feed control [2]. The welding programme for the individual spot is set on this control unit. The instruction "Weld" can be given from the same pendant unit (Fig. 4) as that from which the various functions of the machine are actuated.

The controls for preselection instructions, such as the direction of travel of the beams and undercarriage, the setting for the height of the work, the electrode lift to clear cross ribs and the spot spacing, are arranged at the top of the pendant unit. All the elements for operational instructions, such as single-spot or step-by-step operation, lower, weld, feed movement, etc., are grouped at the bottom of the control unit.

In order to fulfil this function of the machine, the pre-selected spot spacings must be determined with respect to position, for which the magnitude of the feed rate must be measured; this is done digitally by pulses generated as a function of the distance. This is the task of an electronic counter, tapped at the desired spot spacing by means of a pre-selector switch on the pendant unit. Since for the feed motion from one spot to another only allows 1 s at a spacing of 30 mm, the control system employs "building blocks" of the Brown Boveri electronic system at all points where pulses have to be handled extremely rapidly.

To ensure that the electrodes are steered accurately to the desired points, the multiple-disc brake is energized a small fraction of a second before the clutch is released. At this instant the pulse initiating the welding process is already being given to the welding control in order to compensate as far as possible for the operating times of the relays in the control system.

The above description shows that here, to handle large-area workpieces, a welding machine extended to resemble a machine tool has been developed, in which all the working and idle times are covered by preliminary settings. This is a major step towards automation of spot welding, and should be welcomed by many industries in which complicated operations and programmes have to be repeated at regular intervals.

(KME) R. FROMM
T. LUBER

Bibliography

[1] W. ECHNER: Programmgeber für Werkzeugmaschinen. Elektrotech. Z. Edition B, 1960, Vol. 12, No. 18, p. 436–8.

[2] F. GERSPACHER and O. WALDVOGEL: Resistance welding machines with three-phase frequency-changer. Brown Boveri Rev. 1960, Vol. 47, No. 3, p. 180–5.

A GRAPHICAL METHOD OF DETERMINING THE VOLTAGE DROP IN THREE-PHASE SYSTEMS CAUSED BY SINGLE-PHASE RESISTANCE WELDING MACHINES

621.791.76.037:621.3.015.1:518.3

This article deals with the voltage drop in three-phase supply networks caused by the connection of single-phase resistance welding machines; a graphical method is described by which the drop can be quickly determined. Means of reducing the voltage drop are also mentioned.

WHEN planning new installations employing single-phase resistance welding machines, or when new machines are purchased for existing installations, it is important to be able to determine the voltage drop likely to be caused in the mains supply, quickly and as accurately as possible. This is particularly necessary when lighting installations are also fed from the same supply. The effect on electric lighting of voltage drops due to the operation of resistance welding machines has been the subject of exhaustive investigations, the results of which were published some years ago in this journal [1]. It was discovered that in the main spheres, spot and seam welding, the voltage drops regarded as disturbing are of the order of 2 and 0·5%, respectively. These figures are made the criteria for the assessment of mains supply conditions. If possible, they should not be exceeded.

In order to determine the voltage drops in the supply network when subjected to an asymmetrical single-phase load, a graphical method has been developed, with which, instead of using an analytical process for instance, the voltage drop at any point in the network can be determined simply and quickly. But first the following quantities must be known:

P_K = the short-circuit power of the supply system at the points to be investigated.

ψ = short-circuit angle of the supply system at the points to be investigated.

P_S = maximum welding power of the machine to be connected.

φ = phase angle at maximum welding power.

Assuming the supply system on the high-voltage side represents an infinite bus compared with the welding machine power, the short-circuit power can now be determined at any point in the system from the active resistance R and the reactance X of the distribution transformer preceding the machine, plus the overhead line and cable. If this information cannot be obtained from the manufacturers or the electricity company, it can be determined fairly accurately from handbooks. The short-circuit power is then given by

$$P_K = \frac{U_2^2}{Z} = \frac{U_2^2}{\sqrt{R^2 + X^2}},$$ where U_2 is the mains voltage,

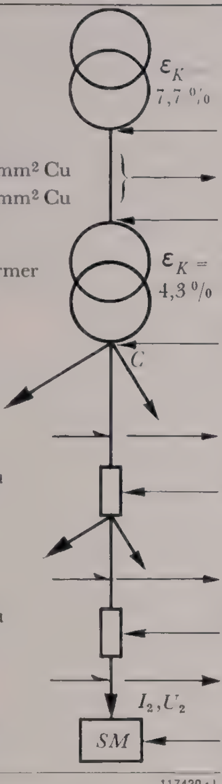
the short-circuit angle by $\cos \psi = R/Z$

These values can also be determined absolutely accurately by means of a measurement with an apparatus built by Brown Boveri specially for this purpose.

The maximum welding power of the machine can be read off the name-plate; likewise the corresponding power factor.

Considering a practical example, the procedure and the graphical method of determining the voltage drops will now be explained. The table opposite, containing the circuit diagram, lists the conditions prevailing in the installation. Suppose a substation is fed from a 50-kV system, regarded as an infinite bus. The 16 000-kVA transformer is connected by cables 1·4 and 0·15 km in length with the 400-kVA factory transformer, which

Numerical example of the calculation of voltage drops in the three-phase supply system u, v, w, caused by the single-phase load imposed by a resistance welding machine with a welding power P_S of 300 kVA, connected as shown in the circuit diagram



Circuit diagram	Voltage kV V	R mΩ	X mΩ	Z mΩ	cos ψ	ψ deg.	P_K MVA	P_S/P_K %	ψ − φ deg.	Voltage drop ε % uv uo	vw vo	wu wo
Substation	50											
16 MVA												
	5.8	20	159	160								
Cables: 1.4 km, 3×95 mm² Cu		270	100									
0.15 km, 3×50 mm² Cu		53	11									
	5.8	343	270	437	0.785	38.3	77	0.39	−24.9	0.71	0.32	0.04
Factory transformer	380	1.47	1.16 ←		convert to 380 V					0.38	0.67	0
		5.2	15.0									
400 kVA	380	6.67	16.16	17.5	0.381	67.6	8.25	3.64	4.4	7.3	1.6	2.0
										5.7	5.2	0
85 m cable,		10	6									
4×150 mm² Cu	380	16.67	22.16	27.7	0.602	53	5.21	5.76	−10.2	11.3	3.8	1.9
										7.6	9.4	0
80 m cable,		12	5.8									
4×120 mm² Cu	380	28.67	27.96	40.1	0.715	44.3	3.61	8.31	−18.9	15.7	6.3	1.6
										9.4	14.1	0
35 m cable,		7	2.8									
4×95 mm² Cu	380	35.67	30.76	47.1	0.757	40.7	3.07	9.77	22.5	18	7.8	1.2
										10.2	16.8	0

ε_K = impedance voltage of the transformers

Data of welding machine *SM*:
I_2 = 37.5 kA
U_2 = 8 V
P_S = 300 kVA
cos φ = 0.45 °
φ = 63.2 °

in turn feeds the spot welding machine *SM* via cables 85, 80 and 35 m in length. Other base loads connected to the factory transformer are not taken into account in calculating the voltage drop because it is only the load peaks originating from the operation of the welding machine that affect the lighting system. Of course, the transformer has to be designed with a rating sufficiently high to cover the sum of all loads.

To calculate the short-circuit powers it is necessary to resort to the table. The resistances *R* and reactances *X* of each element are entered in the table; from them and the impedances *Z* it is now possible to calculate P_K and ψ at each point. The graphical determination of the voltage drops caused by the welding machine requires the expressions P_S/P_K as a percentage, and the difference angle $\psi - \varphi$.

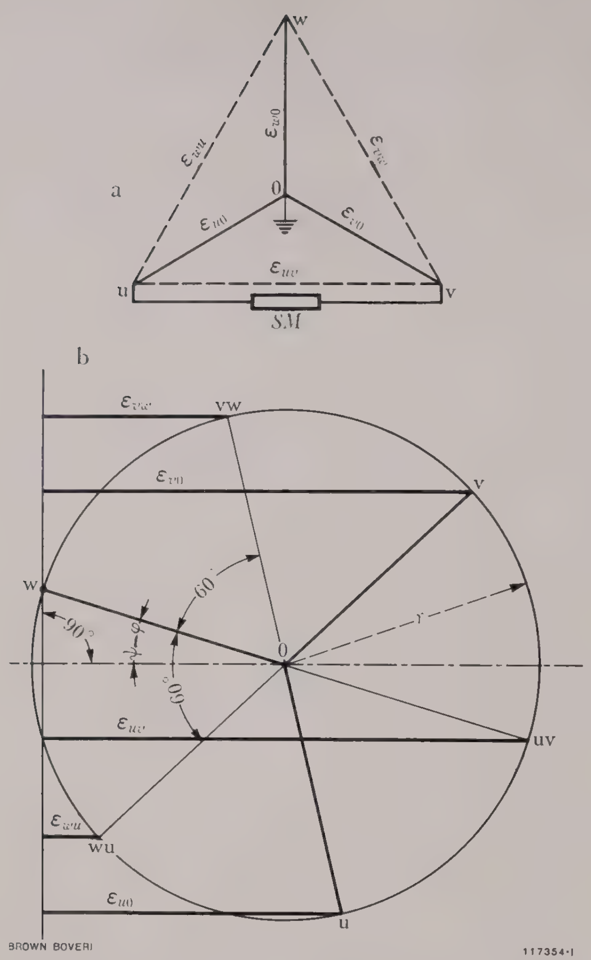


Fig. 1. – Graphical method of determining the voltage drops in three-phase systems, caused by a single-phase load

a: Diagram of the voltage drops ε in the three-phase system u, v, w with earthed neutral 0. Connected between the phases u and v is a resistance welding machine *SM*, representing a single-phase load.

b: Circle diagram, plotted as follows: Starting from the broken-line axis through the point 0 corresponding to the neutral of the system, a diameter w–uv of the circle of radius $r = P_S/P_K$ (%) is drawn at the angle $(\psi-\varphi)$. r gives the scale of the diagram.

The voltage drops (as % of the voltages of the unloaded symmetrical three-phase system) are given by the lines dropped from the points u, v, uv, vw and uw on the circle to the line through w perpendicular to the axis of the diagram.

For explanation of notation, see text.

This method, which not only takes the phase-to-phase voltage drops into account, but also those to earth, utilizes the circle diagram in Fig. 1. In the construction of this diagram it must be borne in mind that the angle $(\psi - \varphi)$ has to be plotted differently according to whether the difference is positive (anti-clockwise) or negative (clockwise).

All voltage drops can be read off this circle diagram (Fig. 1b), in which they are shown as heavy lines. At point *C* in the circuit diagram in the table (secondary terminals of the factory transformer), which is important as the point of connection of the lighting system, the voltage drops ε_{u0} and ε_{v0}, which govern fluctuation in the lighting system, amount to 5·7 and 5·2%, respectively; they thus exceed the figure of 2% which can be permitted without disturbing the lighting.

To reduce these particular voltage drops the following measures may be adopted:

1. Increase the capacity of the factory transformer.
2. Supply the lighting system from a separate transformer connected to the mains on the h.v. side.
3. Improving the power factor of the welding machine, e.g. by means of capacitors.
4. Operating the welding machine three-phase and thus balancing the load on the mains [2].

Each of the above measures is able to reduce the voltage drops to such an extent that they no longer affect the lighting. It is now the task of the project engineer to coordinate the desires of the user of the welding machine on the one hand with those of the electricity company on the other, in such a way that the most satisfactory and least expensive solution can be adopted. When planning the new layout of those parts of the circuit which may have to be added or reinforced, the graphical method described will render valuable service and provide a quick, reliable picture of the conditions.

(KME) H. MEYER

Bibliography

[1] P. WEBER: Voltage drops in supply systems due to resistance welder operation. Brown Boveri Rev. 1950, Vol. 37, No. 8/9, p. 310–18.

[2] F. GERSPACHER and O. WALDVOGEL: Resistance welding machines with three-phase frequency-changer. Brown Boveri Rev. 1960, Vol. 47, No. 3, p. 180–5.

CONTACTLESS CONTROL OF SMALL TABLE WELDING MACHINES USING SILICON THYRATRONS AS POWER SWITCHES

621.791.763.1.03-52

This article describes a control system for table spot welding machines, the control elements of which are exclusively components from the Brown Boveri electronic system, with silicon thyratrons as power switches.

THE PRIMARY task of control systems for electric resistance welding machines is to ensure that exactly the right amount of energy is supplied to the welding point, thereby guaranteeing the quality of the weld and precise reproducibility. The welding energy can be determined by the weld time, expressed in half-periods, and the welding current. The number of half-cycles can be determined either indirectly by simple timing circuits comprising *RC* elements or, when greater accuracy is required, direct by digital counters. The welding current is varied by altering the firing angle α, i.e. the angle (in electrical degrees) between the beginning of a half-cycle of the alternating voltage and the instant at which the power switch (gas-filled thyratron, ignitron or silicon thyratron) closes.

The switching operations that have to be performed by the control system—generating and counting the firing pulses, etc.—have to be carried out very rapidly and exactly, so that to attain the high standard of reliability required, only electronic elements can be considered, such as transistors, diodes and silicon thyratrons.

The control system to which this article is devoted is used in conjunction with a table spot-welding machine and is equipped with elements from the power range of the Brown Boveri electronic system [1–4]. The basic element of this system is the printed circuit module containing the necessary components, such as resistors, capacitors, transistors, diodes, etc. The metal-framed printed circuits are encapsulated in moulded resin (Fig. 1), the connections being taken to a contact system

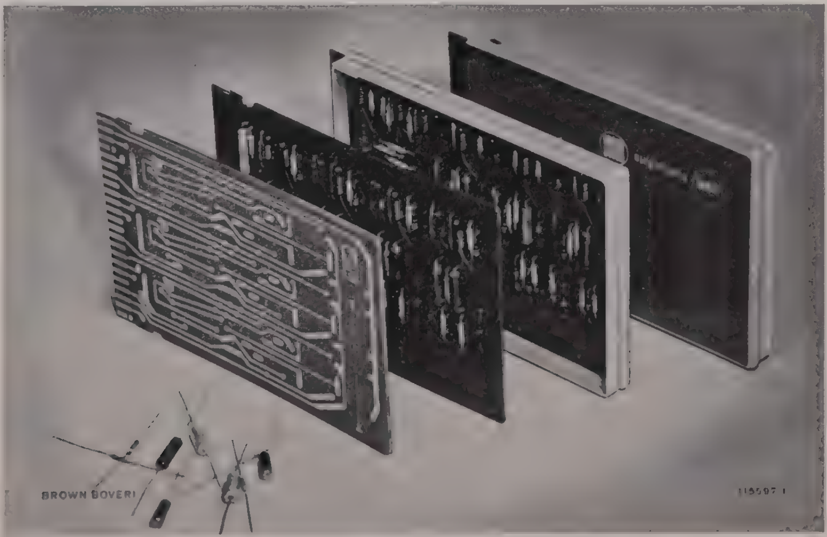


Fig. 1. – Stages in the construction of a module with printed circuit, the smallest "building block" in the Brown Boveri electronic system

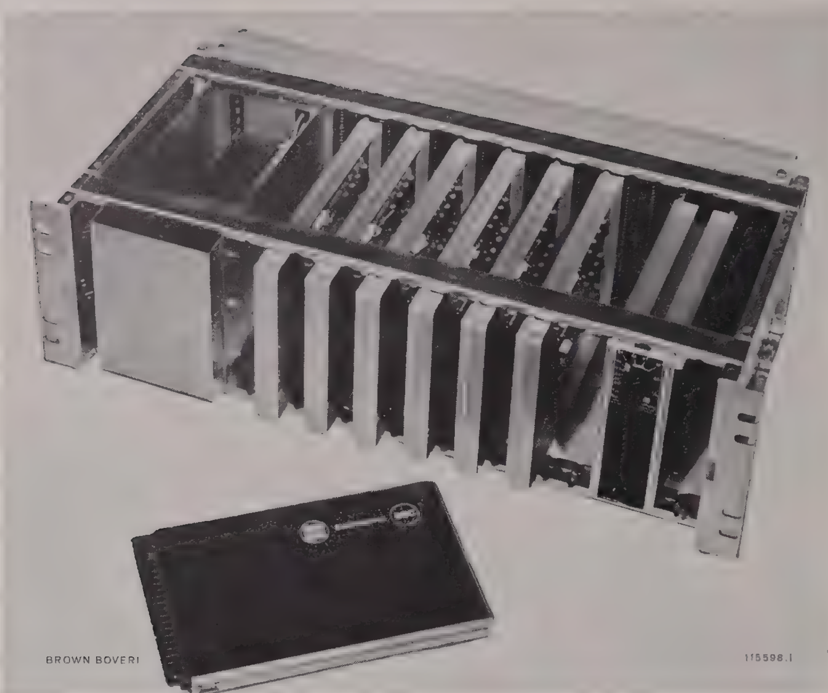


Fig. 2. – Tier capable of accommodating up to 24 modules

with gold-plated contacts. Up to 24 such modules can be housed in a tier (Fig. 2). Several tiers are combined to form a block which, in large installations, is incorporated in a cabinet with a hinged mounting frame. Whereas the modules are of the plug-in type and therefore easily replaced, larger elements are designed as complete sub-units and permanently mounted in a tier. Typical examples are the supply transformers or power packs. For the control system in question two tiers are quite sufficient to house all the necessary elements, including

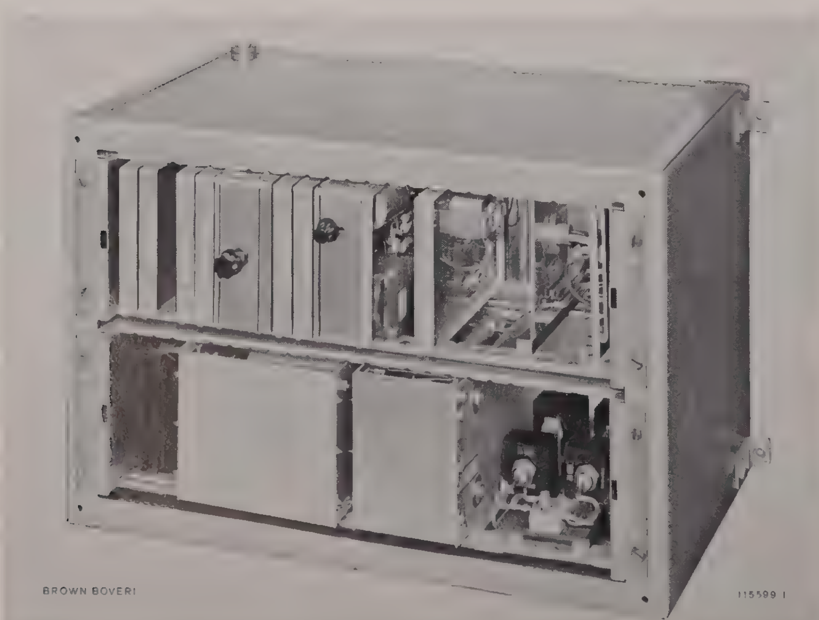


Fig. 3. – Control system for a table spot-welding machine, containing elements of the Brown Boveri electronic system

The dials for the two knobs—for current and weld time—are attached to the front of the casing, which has been removed.

the silicon thyratrons. Fig. 3 illustrates the complete unit with two tiers in a casing, mounted below the table-top of the welding machine.

In the installation chosen as example the machine is used for welding the coiled filaments of double-filament headlamps to the lead-in wires. The welding transformer is connected to a single-phase 380-V supply through silicon thyratrons acting as electronic switches. These thyratrons are controlled silicon rectifiers which can be changed from the blocking to the conducting state by a triggering pulse [5], in much the same manner as gas-filled thyratrons. Once firing has taken place the flow of current cannot be varied, as with the gas-filled thyratrons. Only when the current attains its natural zero does the thyratron regain its blocking capacity, and has to be refired in the succeeding half-wave. Compared with the gas-filled tube, the silicon thyratron is very small in size (see Fig. 4); moreover its power losses are much lower and thus its efficiency is higher because it requires no heating and the voltage drop in the forward direction is much lower than that of the gas-filled thyratron (1–2 V instead of about 20 V).

However, since silicon thyratrons are at present much more expensive than uncontrolled silicon rectifiers, the antiparallel connection normally employed was not chosen in this case, but controlled semiconductors inserted in the d.c. limb of a bridge consisting of uncontrolled silicon rectifiers (Fig. 5). By this means only half as many silicon thyratrons are required as for a full bridge; of course their current-carrying capacity must be twice as high. This arrangement therefore only provides advantages in those cases in which the current capacity of the anti-parallel connection can be utilized at the most by 50%, and where correspondingly cheaper silicon thyratrons having only half the current rating are not available in the range.

Fig. 4. – Comparison between a silicon and a gas-filled thyratron of roughly equal rating

Silicon thyratron:	
Max. inverse voltage	400 V
Sustained current	15 A
Gas-filled thyratron:	
Max. inverse voltage	2000 V
Sustained current	3·6 A

The control system has to fulfil the following requirements:

1. It must be possible to preset the number of welding half-cycles exactly between 1 and 10.
2. The welding current must be infinitely variable by varying the firing point between 70° and 165°.
3. Beginning with a minimum value, the welding current must be able to attain its full value in the third or fourth half-cycle (slope control). This is necessary because, with the initially small contact area, the application of too high a current would result in the current density being too high, leading to spatter.
4. The command to weld is given by a mechanical contact on the machine, which need not conform to any special requirements regarding freedom from chatter or operating time.

These four conditions are fulfilled by the circuit shown in Fig. 5. A pulse generator 2 produces the pulses for the silicon thyratrons 6 by comparing a sinusoidal voltage

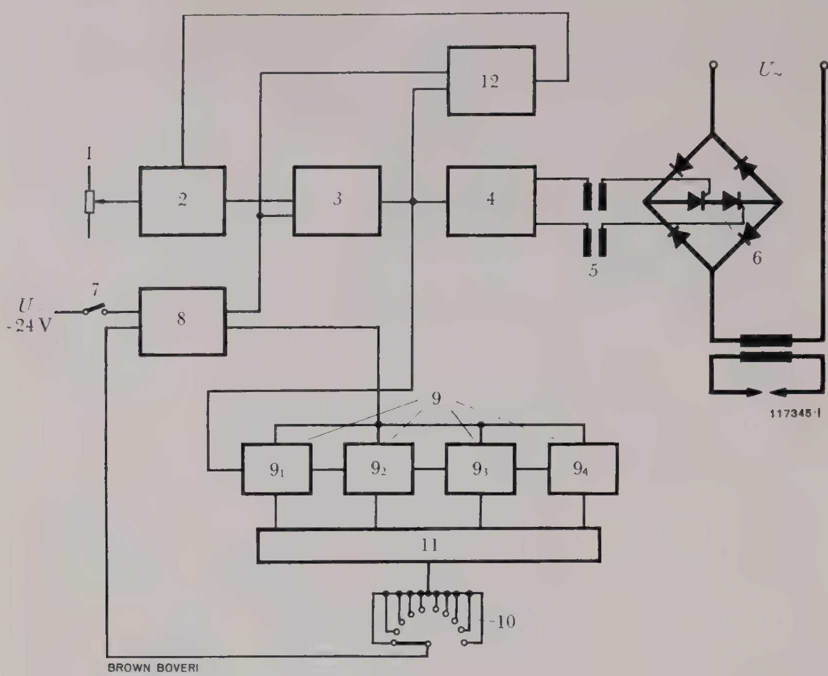


Fig. 5. – Circuit diagram of the welding machine control system

1 = Potentiometer
2 = Pulse generator
3 = AND gate
4 = Pulse amplifier
5 = Insulating transformer
6 = Silicon thyratrons
7 = Switch
8 = Store
9 = Counting decade with 9_1, 9_2, 9_3 9_4 = Binary counting stages
10 = Selector switch
11 = Code converter
12 = Store

synchronous with the mains with a d.c. control voltage. The firing angle α can be set by varying the d.c. control voltage with the potentiometer 1. To begin with, these pulses are not passed on to the pulse amplifier 4 by the AND gate 3. The thyratrons 6 are blocked and no welding current can flow. Only when the switch 7 is closed on the welding machine to start the welding process is the store 8 switched over. Chattering at the contact 7 has no effect as the store changes to a new position on receipt of the first pulse and further chattering pulses do not communicate any new information. As a result of this action the AND gate 3 receives a signal at its second input and now allows the pulses from the pulse generator 2 to the amplifier 4, and via the insulating transformer 5 to the silicon thyratrons 6. The welding current can now commence to flow. The

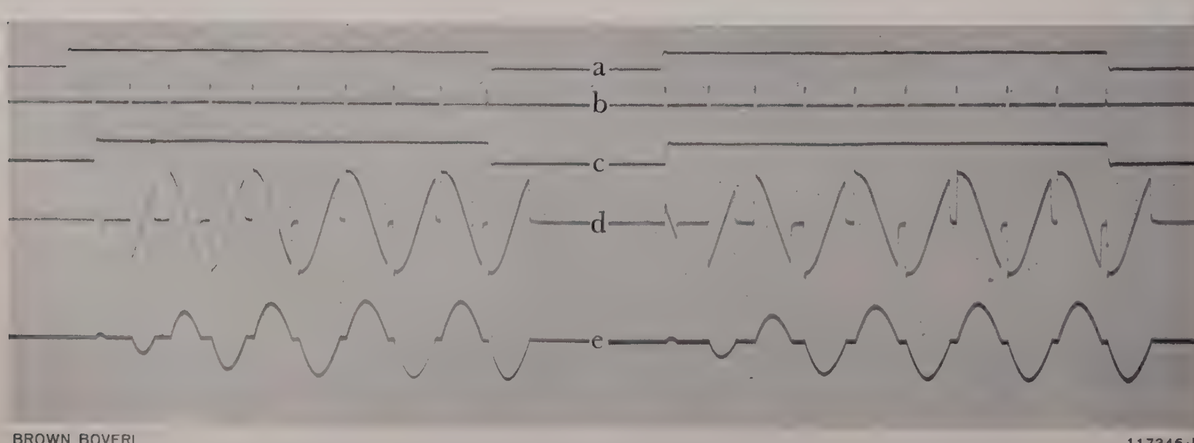


Fig. 6. – Oscillograms of two welding operations with ten half-cycles and full welding current

a: Output voltage of store 8
b: Firing pulse at output of the AND gate 3
c: Output voltage of store 12
d: Primary voltage of the welding transformer
e: Welding current

pulses appearing after the AND gate are passed on to a counting decade 9 consisting of four binary counters and are counted there. The code converter 11 converts the result, in the form of a pure binary code, into a suitable decimal code for the selector switch 10. The first pulse transmitted by the AND gate switches over the store 12, whose output voltage releases an *RC* element in the pulse generator. The voltage at the capacitor, which is simultaneously the control voltage, now increases exponentially with a time constant of about 30 ms to the value previously set with the potentiometer 1. By this means the system ensures that the first pulse is always at the furthest end position, corresponding to a firing angle of 165°, so that the first half-cycle of the welding current contains the desired minimum energy. The second half-cycle is somewhat stronger, the value set on the potentiometer being attained by about the fourth half-cycle.

As soon as the number of half-cycles set on the selector switch has been attained, a signal appears at the root of the switch which switches the store 8 back again, blocking the AND gate 3 and preventing the next pulse from the generator 2 from reaching the silicon thyratrons 6. The welding process is thus ended. The overriding effect of the signal from the selector switch, achieved by suitably designing the store 8, ensures that welding is also ended when, owing to inertia in the operation of the switch 7, the latter is still closed, which could be interpreted as a start signal.

The second output of the store 8 resets the four binary counters 9 to zero. At the same time, by means of store 8, the store 12 is also switched back, discharging the *RC* element in the pulse generator. The control system is then ready to receive the next starting pulse given by switch 7.

Fig. 6 shows oscillograms of two welding processes. It will be observed that, regardless of when the switch 7 closes, the store 12 switches over only at the first welding pulse, so that it is always retarded as much as possible. Thus the rise in the welding current can always be exactly reproduced regardless of when the switch is closed.

With a minor modification to the circuit the weld time can be increased to cover the range of 1–99 pulses. This requires the addition of a second binary counter consisting of four stages, with a code converter and selector switch, thus permitting the extension to the second decimal.

The strict requirements regarding accuracy, long life, and reliability in spite of frequent operation, which the control systems of welding machines have to fulfil, can now be met by employing semiconductor elements. The control system for a table spot-welding machine, as described above, is constructed of standardized elements from the Brown Boveri electronic system which, being free from wear, have a very long life.

(KME)

H. HECKMANN
H. KIELGAS

Bibliography

[1] H. BRÄNDLE, K. STAHL: Fundamental aspects of the Brown Boveri electronic system. Brown Boveri Rev. 1960, Vol. 47, No. 10/11, p. 661–70.

[2] T. ERNST: Design principles of the Brown Boveri electronic system. Brown Boveri Rev. 1960, Vol. 47, No. 10/11, p. 670–5.

[3] R. ZWICKY, M. SYRBE: The Brown Boveri electronic system – closed-loop control. Brown Boveri Rev. 1960, Vol. 47, No. 10/11, p. 676–81.

[4] H. BRÄNDLE, H. LISNER: The Brown Boveri electronic system – open-loop control. Brown Boveri Rev. 1960, Vol. 47, No. 10/11, p. 682–96.

[5] E. WEISSHAAR: The Brown Boveri controlled silicon rectifier CS 100. Brown Boveri Rev. 1961, Vol. 48, No. 3/4, p. 262–6.

SPOT WELDING IN THE FABRICATION OF STEELWORK

621.791.763.1:624.014.2

Hitherto spot-welding machines were generally used only for joining relatively thin sheets, but this process is so economical that it is beginning to prove attractive in the sphere of moderately thick plates. Recently some exhaustive tests were carried out with joints in plates up to 25 + 25 mm thick. Since the manufacturers of welding equipment are able to offer spot-welding machines capable of handling such thicknesses, this opens up quite new aspects for their application in the fabrication of steelwork in general.

AMONG the most important components of steelwork are the connecting media, whose task is to combine the various constructional elements into a static whole. This effect can only be achieved, however, when reliable transmission of all, or only certain particular forces is assured by choosing suitable connecting media, and when the deformation experienced by the entire structure due to the elasticity or plasticity of the connecting media does not exceed the limits compatible to other structural deformations.

The media normally employed for the connection of steelwork are rivets, welded joints, bolts (especially high-tensile bolts) and lately adhesives.

Rivetting, the oldest method of joining steelwork, is robust and dependable, but in view of the work involved and the strength limitations it can no longer be regarded as the "last word". It demands comprehensive, exact drawing and marking-out, accurate machining, production of the raw rivets and, finally, rivetting with the application of heat. From the strength aspect this method is unsatisfactory because it inevitably involves weakening the material, giving rise to stress peaks.

Since the 1930s fusion welding has reached a high standard of development. It is almost perfectly satisfactory when constructional requirements permit a harmonic flow of force. For designs with force deflections, however, it can only be employed under certain conditions, furthermore it imposes much stricter requirements regarding the material. Welding is an ideal method of producing large and complicated cross-sections, but difficulties arise when several plates in a stack have to be joined together, because the edge welds alone are not sufficiently strong.

High-tensile-strength bolts have been used to an increasing extent for steelwork in recent years. Above all, they appear to be an ideal means of dispensing with site welding when large sections can be prefabricated by welding in the factory and bolted together reliably on site. Owing to their extreme rigidity such bolts can easily be combined with welded seams to transmit forces in equal cross-sections.

Adhesive techniques have not progressed very far yet, though if further developed there are prospects of their being utilized in steelwork.

This present review of the experience gained with connecting media normally employed for steelwork indicates the desirability of looking for other possible means. The objectives towards which we must strive are:

From the materials aspect

The use of simple mild and low-alloy steels, which do not impose any special conditions regarding smelting and casting.

From the work aspect

Processes which are insensitive to the normal state of the surface of rolled steel products (skin, slight rust),

which require less preliminary drawing and marking-out, which reduce the amount of machining, and which are versatile and easy to employ.

From the strength aspect

Processes which are not accompanied by any weakening of the material,

which do not produce very high stress peaks, and which do not cause any undesirable changes to the material.

In the foreseeable future it is unlikely that any one process will succeed in fulfilling all the above conditions completely. But since the one or the other method of connection only exhibits disadvantages in relation to the particular constructional possibilities, efforts will be made to adapt other methods of joining where the processes used hitherto cannot at present be regarded as completely satisfactory.

Among these new methods we may count spot welding, provided its field of application can be extended to the steel thicknesses normally employed for constructional steelwork and to the design conditions encountered. This process, which has long been known for joining thin steel sheets and has been employed with great success, has also been used for several years for the construction of steelwork in France, involving material thickness of up to 50–60 mm. The main objects have been heavy supporting pillars, made from a rolled section—such as an RSJ—with reinforcing plates or sections (Fig. 1). Also lattice crane runway girders (Fig. 2), roof trusses and the like are spot welded there. A surprising feature of these spots was that, instead of producing a nugget-formed fusion zone at the contact surfaces of the plates joined, the fusion extends to the full thickness of the material, rather like a rivet but with two shallow depressions in the outer surfaces (Fig. 3). These welds only became feasible after certain perfections had been incorporated in the welding machines, particularly on the electrical side. In these spot-welding machines the transformer is connected to all three phases of the mains and, owing to the need for very good contact between the parts, has to develop an electrode force of up to 14 t. The welding process itself may be divided into the following phases:

Fig. 1. – Example of spot-welded steelwork

Column composed of a basic rolled section reinforced with welded webs.

[This photograph, as well as Fig. 2 and 3, was placed at the author's disposal by courtesy of Messrs. Sciaky, Paris]

- preheating,
- welding,
- maintenance of the pressure during cooling,
- post-weld heat treatment,
- final cooling.

Fig. 2. – The use of spot welding in the production of a lattice crane-rail bracket

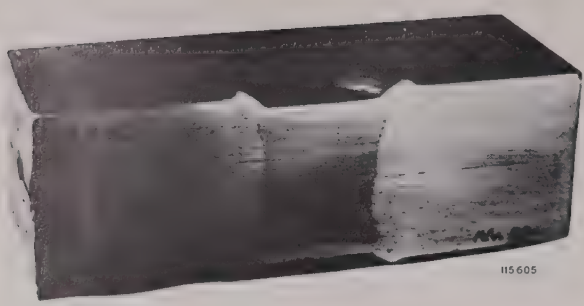


Fig. 3. – Macrograph through a spot weld in 52 steel 20 + 20 mm thick

It is interesting to note that not only a nugget-shaped weld was produced at the point of contact between the two surfaces, but that fusion of the entire thickness took place giving the appearance of a rivet, but with two slight depressions on the outer surfaces.

This development in France encouraged the Deutscher Ausschuss für Stahlbau and the Deutscher Stahlbau-Verband to study the problem in detail. The fact that spot welding has reached the extent sketched above in France is partly due to the absence of official building regulations of the kind laid down in Germany, for instance, the execution of such steelwork remaining the sole responsibility of the constructional engineers. In Germany, though, the use of such a new method of connection can only hope to receive official approval when "Directives for the calculation and execution" of such joints exist, which can only be prepared after theoretical and experimental investigations have been carried out.

Credit is due to Prof. Bierett and Prof. Steinhardt for their work in preparing the theoretical and experimental results required, on behalf of the Deutscher Ausschuss für Stahlbau, who published them as Report No. 23 entitled "Untersuchungen zur Anwendung der elektrischen Widerstandspunktschweissung im allgemeinen Stahlbau" (Investigations into the application of electric resistance spot welding for the fabrication of general steelwork).

Owing to the satisfactory results gained from these investigations, which Prof. Klöppel also regards as adequate, Prof. Bierett prepared his "Provisional recommendations for the use of electric resistance spot welding in the fabrication of steelwork", which have been discussed by various committees concerned with steelwork and which will be published shortly. Now that the Federal Institute for Materials Testing in Berlin has succeeded in clearing up the question of testing spot welds by ultrasonic waves, and the investigations into the economics by various steelwork firms have proved satisfactory, it should be possible for this new method of joining constructional steelwork to be adopted in general practice.

What now are the possibilities for the employment of spot welding in the fabrication of general steelwork?

The investigations, which so far have been performed in series, have proved that it is advisable to distinguish between:

a. constructions mainly subjected to static loads, and

b. constructions subjected to reverse loads.

Those constructions in category a must again be subdivided into steel components subjected to central pressure (composite cross-sections of columns, frame stanchions, etc.), composite bending girders (spot welds between web plates, flange-angles and flange-plates) and frameworks where joints and connections necessitate several spot welds in succession.

For the first two kinds of steelwork construction spot welding, according to the present state of the art, appears perfectly admissible, as well as being practicable from the technical aspect. This is because the shear stresses obtained by calculation of composite cross-sections of columns and solid web girders, no matter how long the row of spot welds may be, will at the most be equalled but never exceeded. For joints and connections, where the supporting cross-section suddenly ends, the number of successive spot welds becomes important when within the payload range there is a very irregular distribution of shearing stresses, corresponding to the rigidity modulus K. Only in this case was it necessary to decide whether, above two or three spots in succession, a larger number could also be permitted. From the experiments which have been performed so

ar, it is believed that there is sufficient elasticity at the shearing areas of the welding point to balance out the shear stresses.

For spot-welded constructions subjected to reverse loads (case b) it is considered, from the few pulsating load endurance tests at the Karlsruhe Technical College, that further favourable results may be expected. Perhaps under the special conditions which have still to be formulated, the load capacity of spot-welded joints subjected to vibrating loads may be about 20 to 30% below that of rivetted joints. At any rate this capacity is quite high enough for occasional fluctuation of an otherwise static load to be absorbed, so that there need be no worries regarding any "change in shape" of such constructions.

Of course it will be necessary to develop new kinds of construction in some cases, as was the case when fusion welding was first introduced. Simply resorting to the old forms used with rivetted joints would no longer conform to the present-day character of steelwork. With the increasing use of wide strip and plate with facilities for folding there is plenty of scope for new designs, a few of which are indicated in Fig. 4 above.

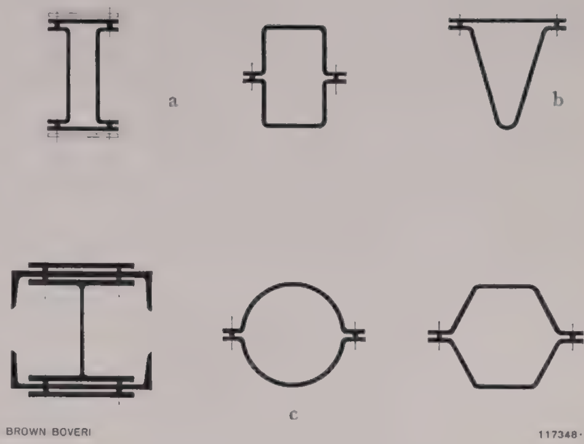


Fig. 4. – Suggested designs for the preparation of pillars and girders from chamfered broad strip

a: Chord and web members
b: Cross and longitudinal girders
c: Pillars

This opens up a wide field of activity for the designer, which can also lead to economical and weight-saving building forms.

(KME)

Prof. W. Wolf
Technische Hochschule
Karlsruhe, Germany

THE USE OF PROJECTION WELDING IN THE MANUFACTURE OF STEEL FURNITURE

621.791.763.2:645.4

This article gives a brief review of the use of projection welding in the manufacture of long pressed parts made from mild steel sheet and the successful application of this process in the production of steel furniture, particularly for drawers of storage cabinets and the like.

General Remarks Regarding Projection Welding

RESULTING from the perfection of electronic methods of control and with the arrival of new designs for welding machines, it may be claimed that resistance welding is the process which has become most widespread, owing to its rationalization of manufacturing techniques in the sheet-metal industries.

In this sector the most remarkable feature is the progress from single-spot to multiple welding which, in contrast to conventional spot welding, allows the welding times to be considerably reduced, and with them the cost of the finished article. Disregarding multiple-spot welding with a large number of single electrodes, or groups, operating in one movement, it led to the introduction and rapid spread of projection welding.

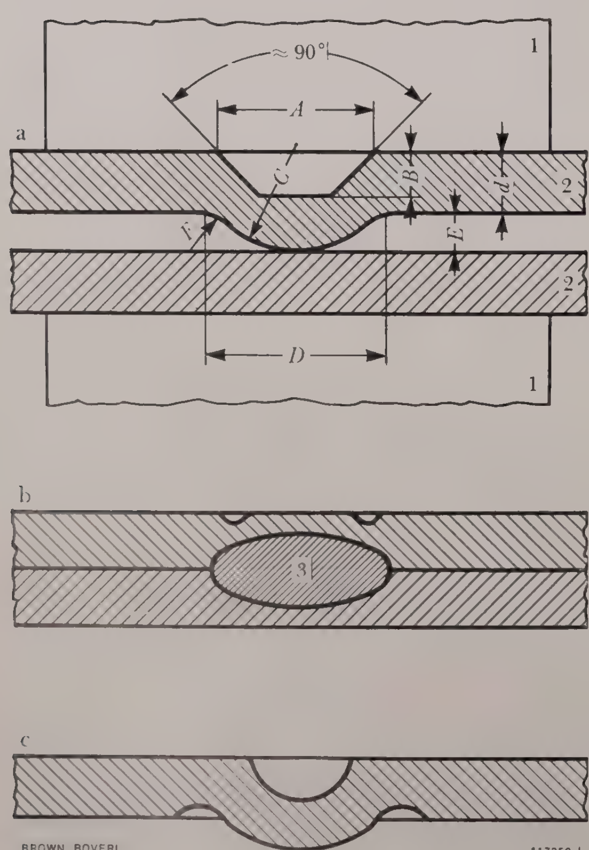


Fig. 1. – The principles of projection welding

Approximate values of dimensions of round projections most commonly used are listed in the table below.

a: Normal round projection before welding
b: After welding
c: The undercut round projection affords the best guarantee for perfect contact between the two parts after welding; there are no gaps caused by excess material.

1 = Electrodes
2 = Metal parts to be welded
3 = Weld nugget

Details of projection dimensions

Thickness of sheet d in mm	Projection size	Dimensions in mm				
		A	B	C	D	$E - F$
0·52–0·70	0·6	2·58	1·00	1·25	3·00	0·71
0·71–0·96	0·8	3·00	1·12	1·40	3·35	0·80
0·97–1·29	1·0	3·45	1·25	1·60	3·75	0·90
1·30–1·82	1·5	4·00	1·40	1·80	4·25	1·00
1·83–2·46	2·0	4·62	1·60	2·00	4·75	1·12
2·47–3·39	3·0	5·30	1·80	2·24	5·30	1·25

This process differs from conventional spot welding in the following points:

- A large number of welds can be executed simultaneously in one movement, without any adverse effects caused by shunting between individual spots. Consequently the minimum spacing of the spots and rows of spots can be smaller.

- The current concentration and the welded cross-section are no longer dependent on the shape and size of varying electrode tips, but are determined by uniform projections in the actual workpiece (see Fig. 1). Generally these projections can be pressed at the same time as the part is stamped or punched, using a combined tool; generally when joining two parts (i.e. when there is only a single contact plane), only one of the parts is provided with the projections.

- The electrode holders and inserts can usually be made solid and large in area, as well as being simple in shape and easy to produce, thus facilitating cooling.

Summarizing, the advantages of correctly prepared and executed projection welds over spot welds are as follows:

- Increased production with a reduced wage bill.

- No inevitable shunts between points of contact.

- More uniform welds and strength values, as well as improved dimensional accuracy of the finished article.

- The welding tools have a longer useful life, owing to the good dissipation of heat by conduction and the lower specific load (welding current and pressure).

- After welding, the unpunched part has a clean, smooth surface and there is no bead on the opposite side.

- Little demand for jigs or clamping devices as in many cases the welding tool itself can be used for this purpose, or augmented by simple means.

- Ideal for batch or mass production of welded steel stamped, drawn or embossed parts.

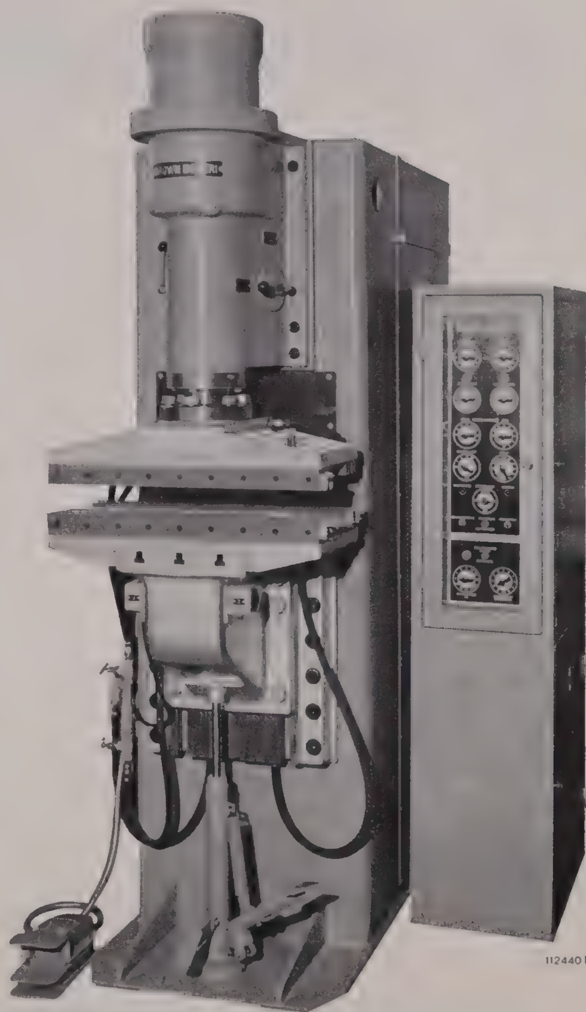


Fig. 2. – Pneumatically operated and electronically controlled projection welding machine for welding long, narrow objects

Clearly recognizable are the special clamping plates with the long, transverse electrodes. With this arrangement on this powerful machine it is, for instance, possible to weld parts of tool-cabinet drawers cleanly and reliably in a single movement by means of rows of spots.

Machine data:

Rated power	180 kVA at 50% duty cycle
Max. welding current with steel	80 kA
Electrode force with 5 atm pressure	3000 kg
with 6 atm pressure	3600 kg

Fig. 3. – Test strips 620 mm long, projection welded in a single electrode movement

Material: pickled mild steel 0·8 and 2·5 mm thick. Number of joints: 10 round projections. The following four kinds of joints can be employed for joining two pieces to one another.

a: Projection in the thinner part. Notice the absolutely smooth surface of the unpunched part of thicker material, which contains neither impressions, shrinkage marks nor tempering coloration.

b: Projections in the thicker part. Owing to the smaller load-bearing capacity of the thinner material the projections can be made correspondingly smaller than normal for the particular thickness. The ring-shaped marks from the projections, though visible after welding, have no proud rim.

c: Parts of equal thickness 2·5 + 2·5 mm. The peel test on the right proves how good the weld is. The surface of the unpunched part exhibits some discoloration, but this does not affect the appearance of the metal.

d: Projections in the thicker part, as with b. The uniformity and soundness of the welds can be judged from the peel test. The projection size used was that for 1·5 mm sheet; apart from some discoloration, the outer surface of the unpunched, thinner part was almost unchanged.

The Basic Problem

These remarkable advantages, as well as new problems posed by customers, induced the Company to investigate to what extent projection welding can be used, beyond the sphere of workpieces of relatively small area, with more or less uniform limits; in particular, the possibility of utilizing the process for welding long parts with different thicknesses of doubly pickled mild steel, from 0·5 to 3 mm thick.

Exhaustive tests—carried out on workpieces up to 100 cm in length—with a Brown Boveri projection welding machine type BU 30, of the normal batch-produced type but with correspondingly wide clamping plates and centrally applied electrode force (Fig. 2), provided the following results:

The process can be employed reliably, without any special precautions, for workpieces up to about 650 mm in length (see Fig. 3), with a maximum spacing of 150 mm between rows of spots parallel to the front of the machine.

Sheets of different thickness can be satisfactorily welded, with one or two contact planes. Without the least restriction this is always possible when the projections are in the thicker part. If the thinner part has to contain the projections, or if it is the only possible part in which they can be produced, the ratio between the thicknesses of the sheets to be joined should not exceed about 3·5:1, when normal round projections, as in Fig. 1a, are employed. With greater rigidity of the projections, achieved by using a punch having an included angle of 60° instead of the normal 90°, this ratio can be increased somewhat. Approximate values for the most common round projections are summarized in the Table below Fig. 1.

The disturbing influence of "skin effect", i.e. the reduction in the cross-section at the centre of the weld, is not experienced. On the other hand, it is

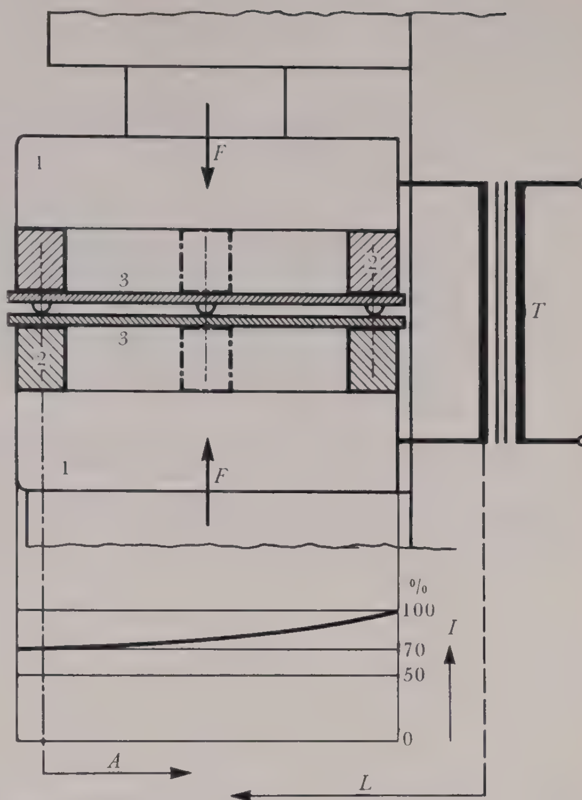


Fig. 4. – Inductive reduction of the welding current

Owing to the relatively smaller throat depth, this effect is smaller with single-phase projection welding machines than with spot welders connected in the same manner. But, assuming the distance between the two clamping plates is kept constant, the increase in distance of the electrode from the transformer causes the current to diminish, and with it the welded cross-section. If the spacing A between two rows of welds, measured from the outermost position of the electrodes, is more than 150 mm, care must be taken to ensure uniform current distribution.

T = Transformer
F = Electrode force
L = Throat depth
A = Distance between two rows of spots, from the outer electrode
I = Welding current in terms of L
1 = Clamping plates
2 = Electrodes
3 = Workpiece

advisable, when welding objects over 65 cm in length, to effect a suitable impedance balance by appropriate choice of the connections for the welding current on the welding tool, thus assuring a uniform current distribution.

As with all resistance welding machines of the conventional design, for projection welding of rows of spots in the direction of the welding transformer, or several rows parallel to the transformer, attention must be paid to the drop in current caused by inductive voltage drop. Their effect is such that a heavier current flows through the projections nearer the transformer than through the outer ones. It can be seen in Fig. 4 that with a normal plate length of 30 cm the welding current I drops from 100% corresponding to minimum throat depth, to 70% at maximum throat depth (as seen from the transformer). If, for instance, various rows of spots parallel to the front of the machine have to be welded, and the electrode spacing of the arrangement illustrated in Fig. 4 is over 150 mm, the current distribution will become inadequate and appropriate counter-measures will have to be taken. This can be done by providing special current leads and inserting insulation between the clamping plate and the associated electrode carrier, or

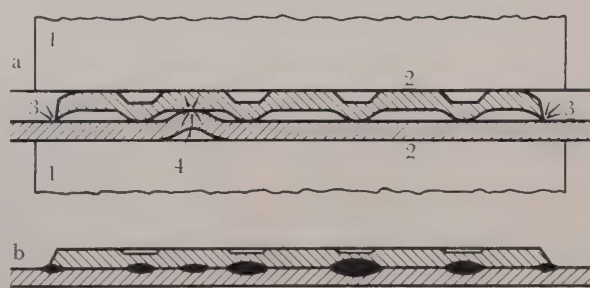


Fig. 5. – Causes of possible, but avoidable faulty welds

Burr, dents, distortion, etc., in the metal to be welded causes shunts, resulting in unequal weld nuggets. The same trouble is encountered when the projection only makes partial contact with the other piece.

a: Poorly prepared material before welding
b: After welding
1 = Electrodes
2 = Parts to be welded
3 = Burr
4 = Kinks, dents, etc.

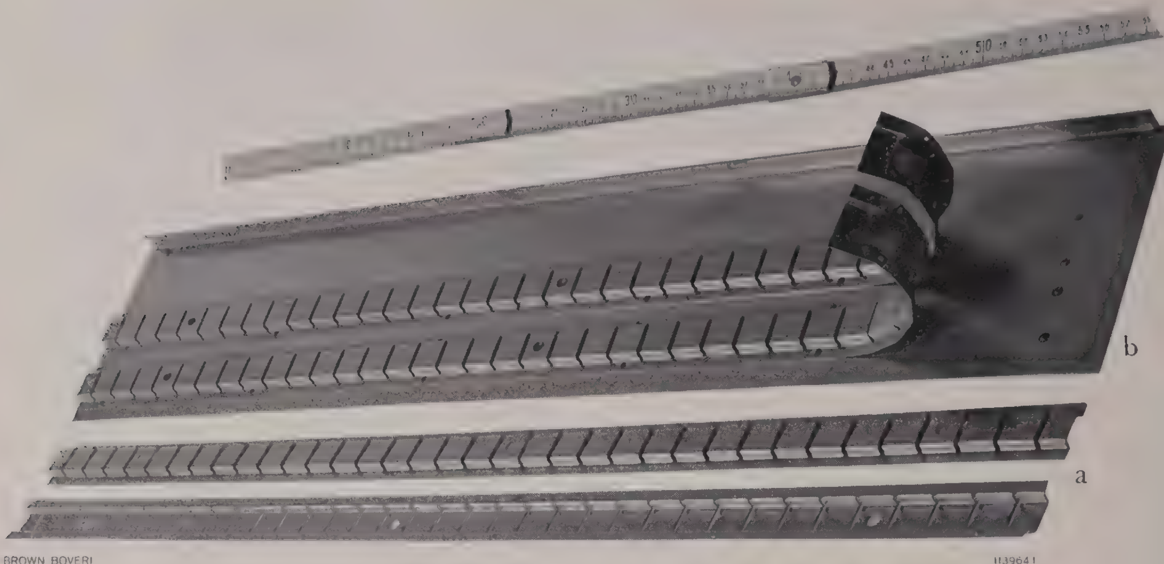


Fig. 6. – Typical case for projection welding on long batch-produced parts of mild sheet-steel

a: Workpieces 0·7 mm thick ready for welding, with 12 round projections automatically punched in during the stamping process.

b: Partition appr. 1·25 mm thick with a pair of slotted bars on each side. All 24 double spots were welded in a single operation and, as the peel test shows, they are perfectly satisfactory.

by using shims and even electrodes of suitable material, having a higher specific resistance.

Unwelcome, but nevertheless avoidable shunts may also occur in projection welding, due to the unsuitable shape or poor preparation of the workpieces. The cause of such shunts are points of contact between the parts of the workpiece, situated outside the projections, which split the path of the current, thus reducing the welded

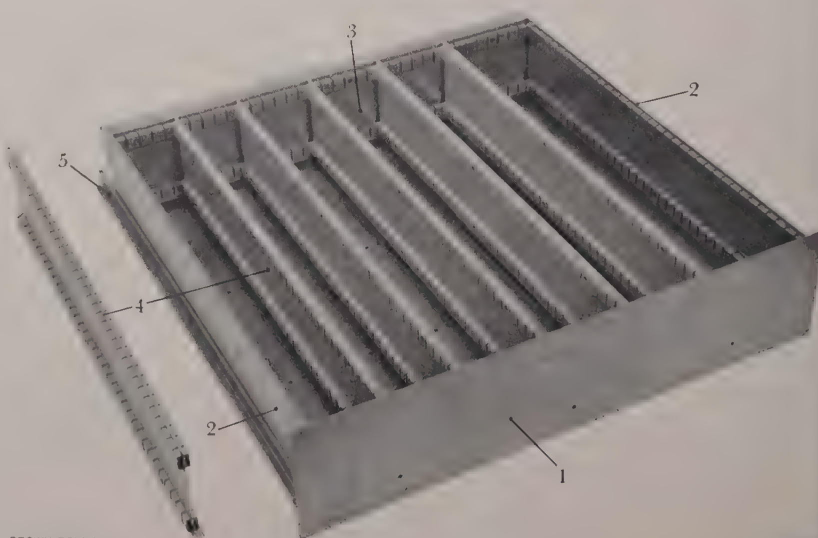


Fig. 7. – Example of tool-cabinet drawer production

Of the 320 spot welds which may have to be performed, depending on the type of drawer and the number of partitions, about 80% can be welded in rows by projection welding. This only requires 12 electrode movements, whereas 264 would be necessary if the spots were welded individually. The resultant reduction in time and wages is obvious and very considerable. The welding tasks comprise the attachment of the slotted bars to the partitions, sides, front and back of the drawer. In special cases the 2·5–3 mm thick runner rails can also be welded to the body of the drawer, using 6–10 projections (see also Fig. 8).

1 = Front panel 2 = Sides 3 = Rear panel 4 = Partitions 5 = Runner rail

cross-section (Fig. 5). For this reason any deformation in the material, such as kinks, dents, etc., occurring particularly in long, narrow parts of thin sheet which are easily deformed by careless handling, must be avoided. The same undesirable phenomena can be caused by edge burr and extreme distortion at the ends of the workpiece. These can also cause shunts and an unwelcome reduction in the size of the weld nuggets.

Applications

As a natural and ideal means of augmenting the projection welding processes which were commonly used hitherto, the above possibilities can be utilized to rationalize manufacture, in all situations where workpieces in the form of long strips or bars, or even plates, have to be welded in large numbers. This is where the correct choice of an appropriately equipped projection welding machine helps to close the gap between the much more expensive multiple-spot welding machine, or double-spot welders employed in groups, on the one hand, and the single-spot unit, with its much smaller productive capacity on the other.

A suitable sphere of application for projection welding in the form described has proved to be the manufacture of steel furniture, especially the production of drawers for storing or tool cabinets, and the like. These objects are indispensable in modern industrial plants. Regardless of whether they are installed as single cabinets containing accessories for a machine, or whether they are combined to form parts stores or tool distribution centres, they save valuable floor space and assure system and order.

Considering that, in a single factory, up to 2000 drawers or more can be combined into units, it is obvious that the components required must be typical mass-produced articles (Fig. 6). Bearing in mind too, that, for instance in the drawer depicted in Fig. 7, up to 320 spot welds have to be executed, it is quite apparent that—as explained below—the choice of the welding process for such objects becomes a vital factor.

If one were to study the particular object, from the point of view of determining how many of these spot

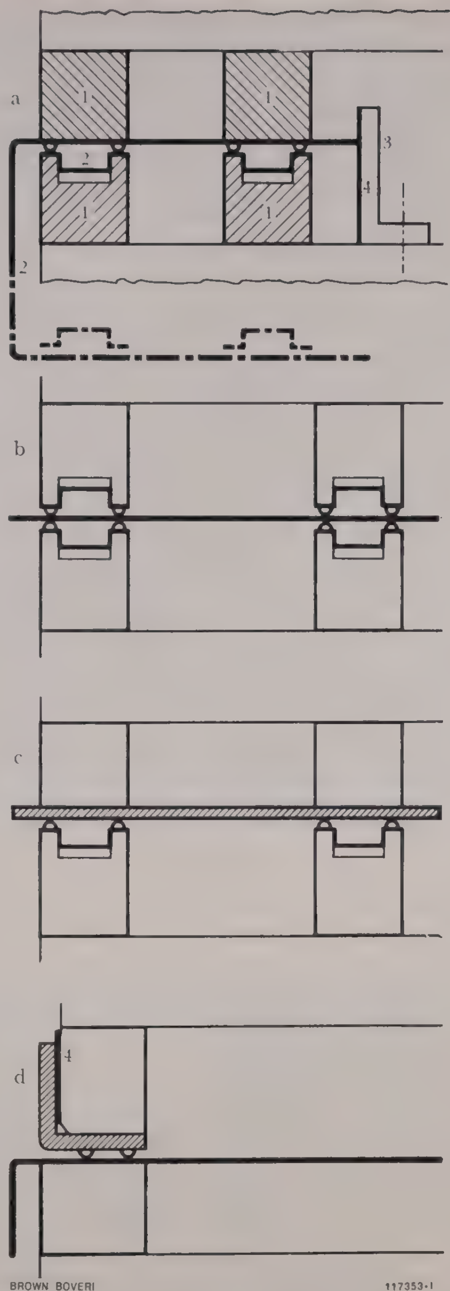


Fig. 8. – Simplified diagram showing the most important welding problems posed by the objects illustrated in Fig. 7, and how they are solved

Material: doubly pickled mild steel sheet

Thickness which have to joined, and the number of welds executed in one movement:

a: 0·64–0·8 mm to 1·25–1·5 mm with 24 spots
b: 0·64–0·8 mm on both sides of 1·25–1·5 mm with 24 double spots
c: 0·64–0·8 mm to 2·5–3 mm with 24 spots
d: 1·25–1·5 mm to 2·5–3 mm with 6–8 spots

1 = Electrodes 3 = Stops
2 = Parts to be welded 4 = Insulation

Fig. 9. – Welding tools and positioning devices

An outstanding feature is the simple form of the electrodes, designed to suit the particular task. For the purpose of the illustration all four electrodes are shown in position. When in operation, however, not more than two would be working at a time. The holding magnets screwed into the upper clamping plate allow the upper workpiece to be placed in position and held firmly. Insulated stops and spacers keep the other parts to be welded strictly true to the dimensions.

1 = Electrodes
2 = Inserted workpiece
3 = Stops
4 = Holding magnets

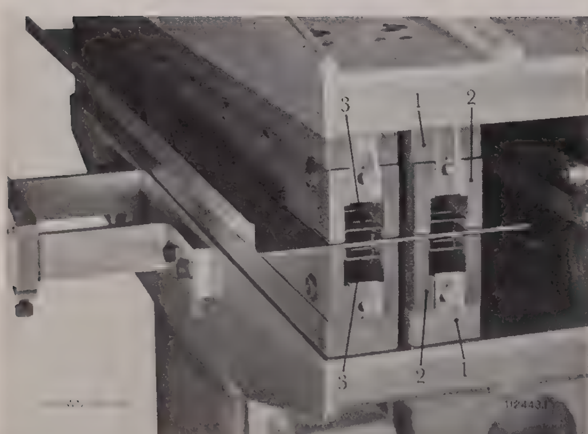


Fig. 10. – Welding parts to both sides of a plate in one operation

The electrodes, which are designed to act as jigs, help to reduce the time spent in setting up the work. The long useful life of these electrodes is remarkable, as they are capable of performing up to 40 000 welds per point before the working surfaces need trimming.

1 = Electrode holders
2 Electrodes
3 = Workpiece

welds can be performed by projection welding, one would arrive at the figure of 264. If these were to be executed by a single-spot welder, they would require 264 movements by the electrode, whereas the projection welding machine can achieve the same result with only 12. The resultant reduction in time and wages is doubtless very considerable. This is supplemented by the much smaller cost of finishing projection welded parts, compared with spot welded parts, because one side of the workpiece is always perfectly smooth, thus eliminating the need for grinding down and trimming of the weld, and the application of several layers of primer before coats of sensitive paint could be applied.

The projection welding operations which have to be carried out mainly involve welding the automatically stamped (with simultaneous pressing of the projections) slotted bars to the front, sides, rear and, above all, the partitions of the drawer. But the runner rails, stop rails, lock-plates, etc., which are usually of thicker material,

can also be reliably joined to the corresponding component. The resultant welding problems and their solutions are schematically illustrated in Fig. 8.

The simple form and arrangement of the welding tools and positioning devices required, the latter being simply insulated stops and spacers, is remarkable. The electrodes, roughly 60 cm long, are of normal commercial wear-resistant electrode bronze, are prismatic in shape, easily interchangeable and, conforming to their purpose, have different numbers of contact surfaces. They are fastened in the clamping plates either direct, or by means of electrode holders (Fig. 9).

Owing to the expedient, easily weldable form of the slotted bars, the welding tool can be used as a jig at the same time, as can be seen in Fig. 10. In the form illustrated they exactly locate the workpieces in their longitudinal axis. The exact location in the transverse sense is defined by an insulated stop at each end of the electrode holder. The parts only have to be inserted in the upper electrodes, where they are held in position by easily dismantled magnets screwed into the upper clamping plate. For the operation described there is no need for the electrodes or their holders to be directly water-cooled because the heat generated is adequately dissipated by the water-cooled clamping plates.

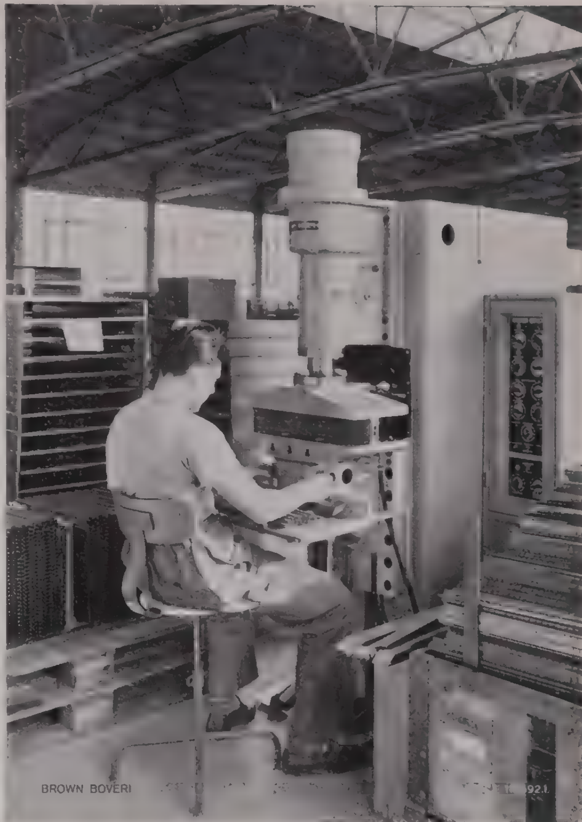


Fig. 11. – Pneumatically operated projection welding machine type BU 30 being used to weld parts of tool-cabinet drawers

This machine replaces seven single-spot welding machines formerly employed for producing the slotted bars on the right of the picture.

Operating Experience

Messrs. Lista (Lienhard-Stahlbau) of Erlen, Thurgau, Switzerland, were well advised to order the first projection welding machine of this kind from Brown Boveri, following detailed planning and consultation, and exhaustive trials. Fig. 11 and 12 depict this machine in operation, performing the tasks described in the foregoing chapter. The machine was taken into service towards the end of the summer 1960, since when it has fulfilled all technical and operational requirements in an ideal manner. The works staff soon became accustomed to handling the machine and its controls, and appreciate, above all, the ease with which it can be operated and its reliability. As has been proved in the meantime, the electrode consumption is extremely small. This is borne out by the remarkable fact that up to 40 000 welds can be executed per spot before the working surface of the electrodes need to be machined down or trimmed. This is an excellent example of the useful life which can be obtained with projection welding electrodes.

In conclusion it is worth mentioning the high productive capacity of this machine which, as far as Brown Boveri are aware, is the first of its kind to be employed for batch welding in the manufacture of steel furniture. Although in this particular installation the amount of projection welding work available cannot keep the machine fully occupied, and it has to be employed for other multiple welding duties, it replaced seven single-spot welders at one blow when it was installed. These machines, and the six operators who were thereby

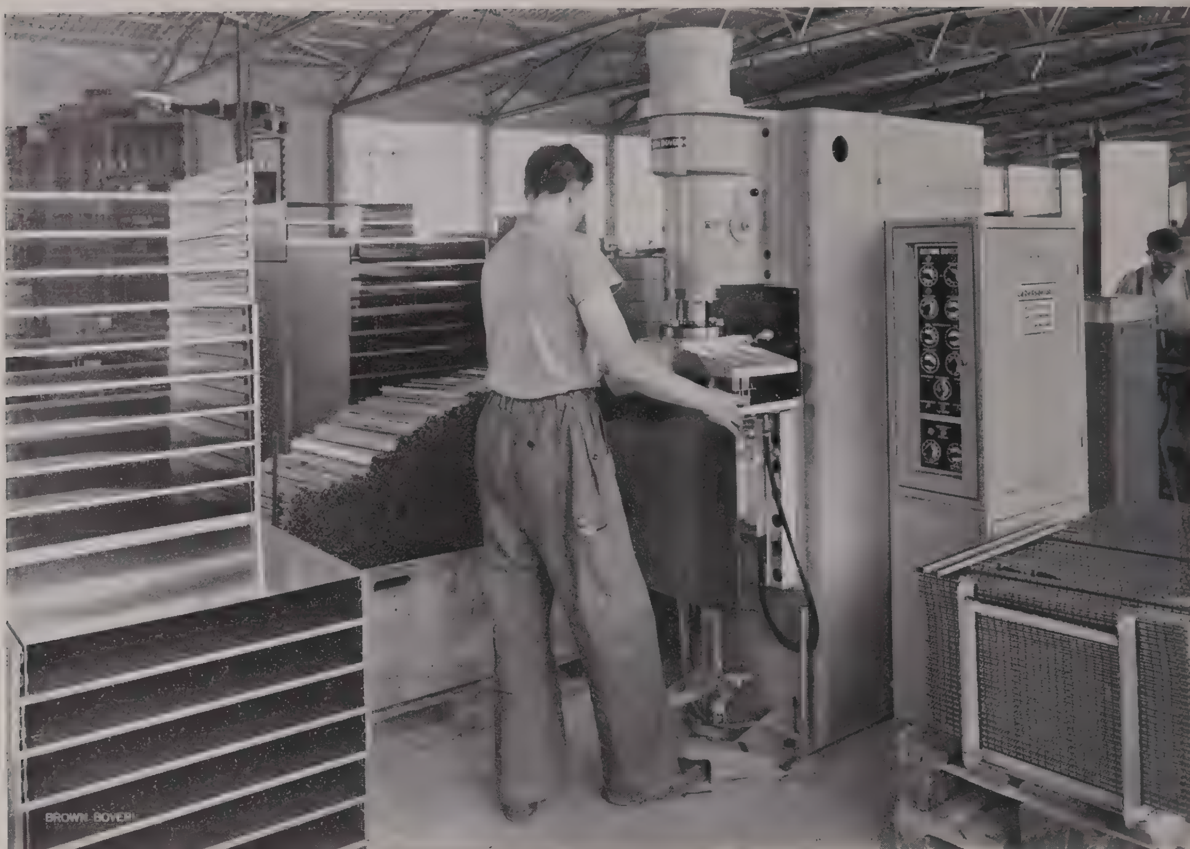


Fig. 12. – The projection welding machine being used to weld the body of a drawer

Since the operator needs both hands to hold the workpiece, he has to operate the machine with a pedal switch. On the left can be seen a pile of completed drawer bodies, while on the right are partitions with four slotted bars welded on in a single operation.

rendered redundant, were thereafter employed for other duties.

The problems encountered in projection welding, and their solutions were dealt with detail in a previous article published in this journal.[1] Therein not only the features and advantages of this special welding process were explained, but also the requirements which the machine and its control system have to fulfil in order to ensure the success of this most economical process.

(KME) K. SCHÄRRER

[1] K. SCHÄRRER: Projection welding, a modern method of joining metal parts. Brown Boveri Rev. 1960, Vol. 47, No. 3, p. 163–79.

BRIEF BUT INTERESTING

New Brown Boveri Welding Rectifiers

621.791.03:621.314.632:546.28

To be able to comply better with the wide variety of wishes and requirements of the Company's customers, the rotating converters which have been a standard welding product for many years have now been augmented by a new design of welding rectifier suitable for manual welding. Fig. 1 depicts a rectifier whose output is infinitely variable between 25 and 270 A. Within this wide range is a special range up to 100 A, intended for welding sheet-metal, for which, as intended, excellent welding properties were attained. At the maximum current of 270 A it is possible to weld with an arcing time factor of 60%, i.e. corresponding to continuous manual welding duty. For this the rectifier cells are so designed that, even with an arcing time factor of 100%, they do not exceed the permitted maximum temperature. Hence, even if the specified arcing time factor were exceeded, the rectifier would suffer no harm. Should the ventilation system fail, all the parts exposed to the heat are protected by an air-flow relay. With this welding unit all conventional types of electrode from 1·5 to 5 mm diameter can be employed in continuous operation, without the least difficulty.

Welding rectifier type G 270

Infinitely variable between 25 and 270 A, with a separate range up to 100 A for welding thin sheet, with special properties for this kind of welding duty. The unit is designed to produce 270 A with an arcing time factor of 60%, but the selenium cells are capable of carrying this current continuously without becoming overheated. Continuous welding is therefore permissible with electrodes from 1·5 to 5 mm in diameter. Built-in main switch with pilot lamp; remote control, if desired.

The novel feature about this rectifier is that the transductor used for controlling the current, and usually mounted separately, is incorporated in the actual supply transformer. In this way much active material is saved, as expressed in the small size, low weight and the resultant mobility of the unit. Also new is the use of wound strip cores of grain-orientated, highly saturable sheet with low losses, and a plastic enclosure which prevents the ever-present stray fields from producing disturbing vibration. The current can be infinitely preset by d.c. premagnetization, thus permitting remote control, if required. A pilot lamp next to the main switch on the control panel lights up when the unit is switched on.

This rectifier unit is not intended for use in shipyards or chemical works as it is unsuitable for use in salty or acid-laden atmospheres. It contains selenium cells with special varnish and edge-protection treatment, which experience has proved to be satisfactory in ordinary welding installations. For special requirements silicon cells can also be incorporated.

The largest rectifier unit in this range is reserved for a general field of applications, but can be employed with automatic arc welders under certain circumstances. It has silicon diodes with a continuous current rating (arcing time factor of 100%) of 550–600 A. Otherwise, as regards design and principle, it corresponds to the 270-A welding rectifier described above.

(KME) H. Kocher

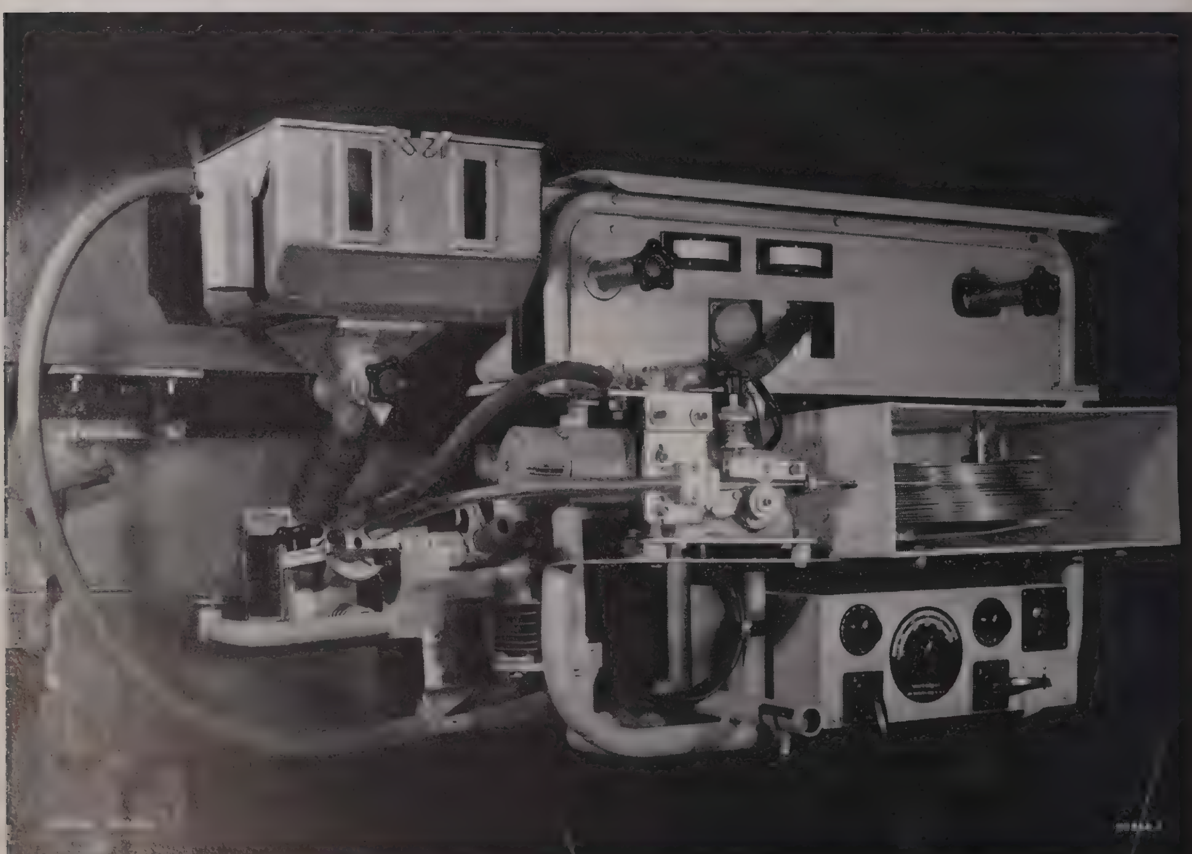
Automatic Arc Welding with Horizontal Electrode in the Production of Large Storage Tanks

621.791.75-52:621.642

THE NEED to store large quantities of liquid hydrocarbons (oils and fuels of all kinds) has led to the construction of tanks whose size and number grow from year to year. Normally these are in the form of vertical cylinders capable of holding many thousand cubic metres; consequently their diameters and heights are very large indeed.

Whereas in most industries automatic arc welding soon made rapid progress, it was necessary to adhere to manual welding for the fabrication of such storage tanks because the majority of the seams have to be welded horizontally from the side, or vertically upwards.

The tasks which automatic welding has to perform are very difficult because, on the one hand, sufficient power has to be available to enable plates 6–32 mm thick to be welded while, on the other hand, the molten pool must not be able to collapse under the weight of



Special automatic arc welder used for the fabrication of large storage tanks

This photograph, which was taken in the test laboratory, shows the welder with the flux hopper, top left, slightly below it the rail on which the unit runs under its own power. Further down is the joint in which the lead roller runs; bottom right is the control unit with the Brown Boveri control system for the wire feed. The whole unit only weighs about 150 kg.

the workpiece. Furthermore, the molten pool must be adequately protected because the seams are subjected to very strict quality tests, according to the specification.

Considerable research has been carried out in recent years into the problems of welding on a vertical surface. Some of the investigations were crowned with success, the solutions which have been adopted lately having given rise to automatic welders which are quite extensive installations. They weigh several tons and for operation on site necessitate lifting and other auxiliary equipment such as has never been used for welding hitherto. Consequently such an installation represents quite a heavy investment.

Owing to their conception, these units, which run along the top edge of the plates being welded, have brought about some drastic changes in the methods of assembly of the tanks. The conventional procedure adopted with manual welding is for the entire tank to be assembled and tacked before welding. However, the use of automatic welders of the type described does not permit an upper row of plates being put into position before the row beneath has been welded. As a result the building material has to be stored longer, so that erection becomes more expensive if only one such tank has to be erected, on account of the times during which the welders are idle. On the other hand when automatic arc welders are employed—usually in pairs, one on either side of the tank—the plates have to be very accurately prepared without any bevelled edges. This means that a tank prepared for automatic welding cannot possibly be welded by hand, and vice versa.

In close collaboration with a well-known French manufacturer of storage tanks—Etablissements Tissot, Podensac—the French associates of Brown Boveri, NORMACEM, Lyons, have devised a lightweight automatic unit, weighing only 150 kg, which allows conventional erection material to be used, of the kind previously employed for manual welding. This automatic welder, which was specifically developed for welding on vertical walls, thus offers the advantage of being suitable for employment in situations where the seams have been prepared for manual welding. Thus the tanks can be completed by the normal methods, the welding process being either manual or automatic, as preferred. In the latter case a number of machines can be in operation simultaneously.

The new special automatic arc welder is a rigidly assembled unit which runs on two rollers on an angle-iron rail attached to the wall. The Brown Boveri system used in the type EV 1000 welder attends to the wire feed, the flux being held together at the arcing point by a special flux chamber. By means of a closed-circuit system the flux is kept circulating, the flux not consumed during welding being augmented by fresh flux and automatically returned into the circuit. This assures perfect uniformity in the quality of the deposited weld metal.

The nozzle guiding the wire, and the flux chamber are articulated in such a manner that the wire is automatically pointed at the joint. The operator has merely to watch the machine and replenish the supply of flux and wire when needed.

Normally the welder is mounted on the outside of the tank. Effective penetration is assured by the application of an internal layer of flux. The rolling system, however, would also permit the machine to be used for welding from the inside. The leading roller is pivoted, allowing the machine to be employed on tanks down to 6 m in diameter.

A special wire-flux combination has been developed which takes into account the various problems associated with the metallurgy and weldability, and encountered in the course of the development. Owing to the excellent cooperation and exchange of experience between a user and the welding machine manufacturer it was thus possible to produce in a short time, not only a complete unit, but also suitable auxiliary material. The first-class combination of all these elements has resulted in a considerable increase in the welding speed, without the methods and auxiliary equipment used for erection having to be changed.

(KME) M. MORIN

Pneumatically operated projection welding machine type BU 30 being used to assemble parts of tool-cabinet drawers

Published by Brown, Boveri & Company, Limited, Baden, Switzerland. Printed by Conzett & Huber, Zurich, Switzerland

Obtainable direct from the publishers